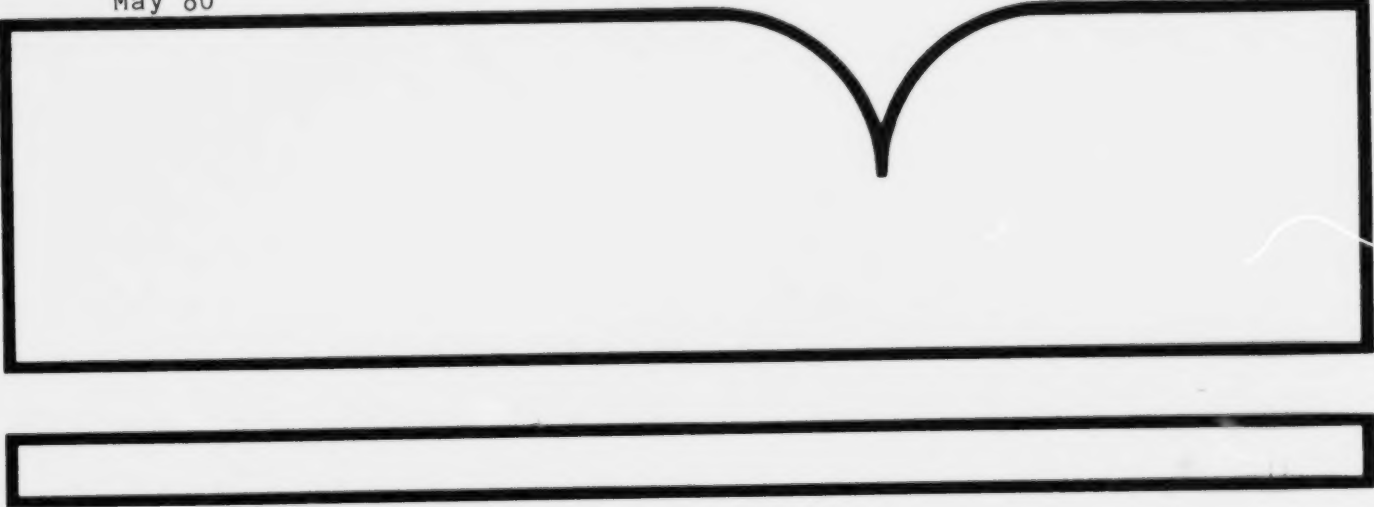


TI-59 Programmable Calculator Programs for
In-Stack Opacity, Venturi Scrubbers, and
Electrostatic Precipitators

(U.S.) Industrial Environmental Research Lab.
Research Triangle Park, NC

May 80



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Research Triangle Park NC 27711

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Measurement	Electrostatic Precipitators	Particulate	14B
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Washington, DC 20460

ABSTRACT

The basic concepts of in-stack opacity as measured by in-stack opacity monitors are explained. Also included are calculator programs that model the performance of venturi scrubbers and electrostatic precipitators. The effect of particulate control devices on in-stack opacity can be predicted by using these programs. The size distribution data input can be either in lognormal or histogram format. The opacity is calculated by using Deirmendjian's approximation to Mie series to obtain extinction efficiencies. Also an alternative opacity program employing the exact Mie series solution is described. The running time for this program is approximately 8 hours while the running time for the approximate program is 30 minutes. The accuracy of these programs is as good as the measured data input.

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SECTION 1

INTRODUCTION

This report has three basic objectives:

1. Provide a handbook for calculating in-stack opacity for particulate control devices on a Texas Instrument, Inc. TI-59 programmable calculator.
2. Describe the latest versions of calculator programs to simulate electrostatic precipitators (ESPs) and scrubbers.
3. Explain the basic concept of in-stack opacity as measured by in-stack opacity monitors.

Developments in calculator technology have allowed mathematical modeling of particle collection in venturi scrubbers and ESPs using a Texas Instrument, Inc., SR-52 programmable calculator as described by Sparks (1978). The development of the more sophisticated TI-59 makes it possible to extend the capabilities of the Sparks' models, especially the ESP model.

Applications of the scientific programmable calculator to gas cleaning technology are further extended in this report to calculations of in-stack opacity. Predicting in-stack opacity is essential for designing control devices to meet strict opacity limitations. The advantages of using a programmable calculator for this purpose are its convenience, inexpensiveness, and simplicity of operation, when compared to a large digital computer.

This report can be viewed as a handbook for calculating in-stack opacity using the output of control device models or as an independent vehicle to compute opacity for given stack conditions.

Calculator programs were developed for a Texas Instrument, Inc., TI-59 programmable calculator with a PC-100A printer. Opacity programs were designed to interface with the ESP and scrubber programs as much as possible. The SR-52 scrubber program was rewritten to conform with the more compact TI-59 coding and to provide data on the outlet particle size distribution. The ESP model is totally new.

Calculator programs are summarized in Table 1. The function of each program, the required data input, and compatible programs are also provided.

The user has a choice of three different in-stack opacity programs (Figure 1), depending upon the type of particle size distribution and particle index of refraction. The opacity calculation procedure for a control device is outlined below. A sample calculation is presented in Section 3.

1. Obtain required data.
2. Select control device.
3. Run control device program.
4. Check output of control device program. If particle size output is in lognormal form, use opacity program No. 1 for lognormal case. If particle size output is a histogram, use opacity program No. 2 for histogram case. Use opacity program No. 5 if the index of refraction is not in following ranges:

$$1.0 \leq \text{real part} \leq 1.5$$

$$0.0 \leq \text{imaginary part} \leq 0.25.$$

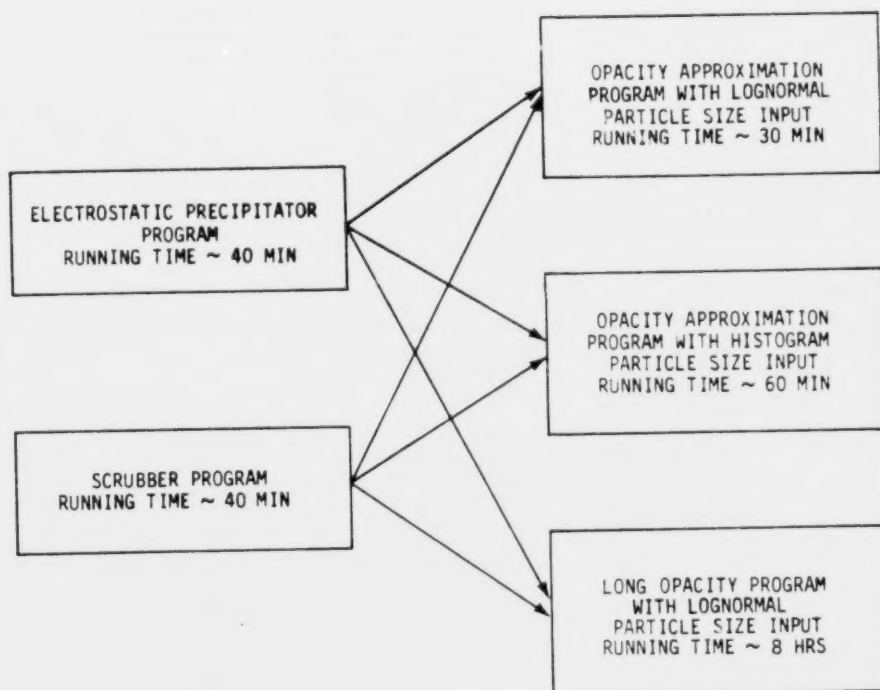
The best lognormal fit of size data is required for this program.

5. Check opacity results:
 - a. If opacity is too high, increase the specific collection area (SCA) for ESP or increase the pressure drop (ΔP) for scrubber.
 - b. If opacity is too low, decrease SCA for ESP or decrease ΔP for scrubber.

The approximate opacity programs require that the index of refraction be in the ranges 1.0 to 1.5 for the real part and 0.0 to 0.25 for the imaginary part. The long opacity calculation, which is valid for any index of

TABLE 1. CALCULATOR PROGRAM SUMMARY

Program	Calculation	Input required	Can be used with:
1. Approximate Opacity (lognormal)	In-stack opacity on lognormal particle size distribution	Stack diameter, mass concentration, density, index of refraction, wavelength, geometric mass mean diameter, geometric standard deviation	ESP, Scrubber Program with lognormal distribution
2. Approximate Opacity (histogram)	In-stack opacity on histogram particle size distribution	Stack diameter, mass concentration, density, index of refraction, wavelength, histogram distribution (mass fractions at particle diameter)	ESP, Scrubber Program with histogram distribution
3. Extinction Efficiency Approximation	Approximates light extinction efficiency for spherical particles	Particle diameter, index of refraction, wavelength	- -
4. Long Extinction Efficiency	Exact light extinction efficiency for spherical particles	Particle diameter, index of refraction, wavelength	- -
5. Long Opacity (lognormal)	In-stack opacity on lognormal distribution	Same as for Program 1, above	ESP, Scrubber Program with histogram distribution
6. Electrostatic Precipitator (histogram)	Penetration in ESP for each particle size and overall penetration outlet concentration for each particle size	Particle diameter, time increments, wire to plate spacing, applied voltage, ion speed, ion mobility, current density, dielectric constant, temperature, viscosity, pressure, specific collection area, precipitation length, gas velocity, normalized standard deviation, gas flow, number of sections, sneaka, fraction of sneaka, histogram particle size distribution	Opacity Program with histogram distribution, or lognormal distribution
7. Scrubber (histogram)	Penetration and outlet concentration of scrubber for each particle size. Overall penetration	Temperature, pressure factor of $\sim (0.5)$, no. of particle diameters, liquid to gas ratio, gas velocity, viscosity, liquid density, particle density	Opacity Program with histogram distribution or lognormal distribution



79-272/1

Figure 1. Relationship between control device programs and opacity programs.

refraction, requires a running time of approximately 8 hours. The approximation programs run 30 minutes for the lognormal particle size input and 60 minutes for the histogram particle size input. The error generated by these programs ranges from 5 to 20 percent depending upon particle size distribution. These programs are generally as accurate as the input data; i.e., the errors introduced by the programs are generally less than the errors in the input data. A large digital computer is unlikely to provide better answers unless the input data are essentially free of error.

SECTION 2

CONCLUSION

The calculator programs presented provide a convenient, useful prediction of (1) in-stack opacity, and (2) the influence of venturi scrubbers and ESPs in controlling in-stack opacity. The advantages of these programs include savings of time, money, and effort.

The analysis of both the calculation of in-stack opacity and measurement of opacity parameters shows that error in the calculator programs is less than the measurement error of approximately 20 percent. The ability to predict in-stack opacity depends on the quality of measurement methods, especially particle size.

A major restriction in using the approximate opacity programs is the exclusion of highly absorptive aerosols. The long opacity program is especially designed to predict opacity for highly absorptive aerosols with lognormal distributions. If the size distribution is not lognormal, then either a computer should be used or a lognormal approximation should be made. A major restriction in using the lognormal size input is that the geometric standard deviation of the size distribution should be greater than or equal to 1.009.

SECTION 3

OPACITY AND CONTROL DEVICE PROGRAM INTERACTION

This section is an example of the procedure used to calculate the effect of a particulate control device on in-stack opacity. Since individual programs are detailed in later sections, only information regarding general operation is covered here.

The following problem illustrates the relationship between the opacity and control device programs.

ESP DESIGN FOR OPACITY CONTROL

Suppose the objective is meeting an opacity limitation of 3 percent on a coal-fired utility boiler. The best way to reach this objective may be to use an ESP as the control device. The following information is required to compute the required specific collection area for the ESP:

Inlet grain loading - 3.5 g/m^3

Remember, all mass concentrations and volumetric flows for this report are at actual, not standard, conditions.

Inlet particle size distribution -

<u>Particle Diameter, μm</u>		<u>Mass Fraction</u>	
0.2	Register 25	0.0001	Register 41
0.5	Register 26	0.002	Register 42
0.8	Register 27	0.004	Register 43
1.5	Register 28	0.07	Register 44
2.5	Register 29	0.15	Register 45
4.0	Register 30	0.25	Register 46
8.0	Register 31	0.35	Register 47
10.0	Register 32	0.4	Register 48
12.0	Register 33	0.3	Register 49

Stack diameter = 7 m
Particle refractive index = $1.5 - 0.002i$
Particle density = 2.5 g/cm^3
ESP wire-to-plate spacing = 0.1143 m
Applied voltage = 30 kV
Ion speed = 528 m/sec
Ion mobility = $3 \times 10^{-4} \text{ m}^2/\text{V-sec}$
Resistivity = $6.71 \times 10^{10} \text{ ohm-cm}$
Current density = $1.3 \times 10^{-4} \text{ A/m}^2$ (calculated from resistivity)
Dielectric constant = 100
Temperature = 150°C
Viscosity = $2.3 \times 10^{-4} \text{ poise}$
Pressure = 76 cm Hg
Precipitator length = 8 m
Gas velocity = 1.25 m/sec
Normalized standard deviation of gas flow = 0.25
Number of sections for sneakage = 4
Sneakage fraction = 0.1

CALCULATION PROCEDURE

1. Estimate SCA to meet desired opacity.
2. Since particle size distribution is in the histogram format, run corresponding ESP program.
3. Obtain outlet size distribution and total mass concentration.
4. Check to determine if size distribution is lognormal.
5. If size distribution is lognormal, use lognormal opacity program. Otherwise, use histogram opacity program.
6. Compare computed opacity with desired opacity. If computed opacity value is too high, use larger SCA for the ESP program. If computed opacity value is too low, use smaller SCA.
7. Run ESP program with revised SCA.
8. Obtain new outlet size distribution and total mass concentration.
9. Use same opacity program from Step 5.
10. Compute new opacity.

Repeat Steps 6 through 10 until calculated opacity approximates design opacity.

SAMPLE CALCULATION

1. Let $SCA = 160 \text{ m}^2/\text{m}^3/\text{sec}$.
2. Run histogram ESP program (program No. 6).
 - a. Turn on calculator.
 - b. Push 1; enter side one of card 1. Push 2; enter side two.
 - c. Push A to enter following data.
 - d. Follow calculator prompting. Enter data; push R/S after each entry.

The following is the printing of data entry.

<u>Calculator Prompting</u>		<u>Data to be Entered</u>	
ESP	ID	1.	ESP identification
	NP	9.	Number of particle diameters
	NN	5.	Number of time increments (5-10)
	H	0.1143	Wire-to-plate spacing, m
	U	3.04*	Applied voltage, kV
		2.6246719 05 EA	Average field
		1.4998125 05 EF	Field at plate, V/m
	V	5.28 02	Ion speed, m/sec
	B		Ion mobility, $\text{m}^2/\text{V-sec}$
	J	3.-04	Current density, A/m^2
		1.3-04	Ion density, number/ cm^3
		1.031875 13 ND	Dielectric constant
	K	100.	
	T	150.	Temperature, $^{\circ}\text{C}$
	VIS	2.3-04	Viscosity, poise
	P	76.	Pressure, cm Hg
	SCA	160.	$\text{m}^2/\text{m}^3/\text{sec}$

* The calculator printout: $3.04 = 3 \times 10^4$. Press 3 EE 4 +/-.

LENGTH		Length of ESP, m
VEL	8.	Gas velocity, m/s
SIGMA	1.25	Normalized standard deviation of gas flow
NS	0.25	Number of sections for sneakeage
S	4.	Sneakage fraction
	0.1	

Store particle diameters from page 7 in Registers 25-33.

- e. Push Trace
- f. Enter smallest diameter and push STO 25.
- g. Enter next larger diameter, push STO 26, etc.

Store corresponding mass fractions from page 7 in Registers 41-49.

- h. Enter mass fraction corresponding to smallest diameter and by pushing STO 41, etc.

Store data on a magnetic card for future use.

- i. Push 3, 2nd, write; enter side one of magnetic card labelled data card.
- j. Push 4, 2nd, write; enter side two of magnetic card labelled data card.

Inactivate trace mode.

Run card 2 of program No. 6.

- k. Push 1; enter side one of card 2. Push 2; enter side two.
- l. Push A.

The following output is printed:

2. -01	=D	Particle diameter, μm
6.4 00		Residence time, sec
7.9718505-09		Ideal penetration x mass fraction ($P_t(d) \times f_i$)
7.9718505-05		Ideal penetration ($P_t(d)$)
5.8981305-02		Ideal migration velocity ($W(d)$)
4.3768619-03		Corrected penetration ($P_t(d)$)
4.3768619-07		Corrected penetration x mass fraction ($P_t(d) \times f_i$)

5. -01 =D
6.4 00

8.7470295-07
4.3735147-04
4.8343334-02
7.7933055-03
1.5582611-05

8. -01 =D
6.4 00

1.4283314-06
3.5705784-04
4.961003-02
7.2059683-03
2.8823875-05

1.5 00 =D
6.4 00

2.2571985-06
1.1285992-04
5.6808519-02
4.853973-03
9.707946-05

2.5 00 =D
6.4 00

3.252111-06
2.168074-05
6.7119289-02
3.1595545-03
4.7393313-04

4. 00 =D
6.4 00

6.9826371-07
2.7930788-06
7.9927289-02
2.2569389-03
5.6423473-04

Particle diameter, μm
Residence time, sec

Ideal $P_t(d) \times f_i$
Ideal $P_t(d)$
Ideal $W(d)$
Corrected $P_t(d)$
Corrected $P_t(d) \times f_i$

8. 00 =D
6.4 00

1.9540703-10
5.5830579-10
1.3316321-01
5.5830579-10
1.9540703-10

1. 01 =D
6.4 00

2.0348601-12
5.0871501-12
1.625269-01
5.0871501-12
2.0348601-12

Particle diameter, μm
Residence time, sec

Ideal $Pt(d) \times f_i$
Ideal $Pt(d)$
Ideal $W(d)$
Corrected $Pt(d)$
Corrected $Pt(d) \times f_i$

1.2 01 =D
6.4 00

1.398674-14
4.6622467-14
1.9185434-01
4.6622467-14
1.398674-14

3.5186328-06
1.1800917-03

Ideal overall penetration
Corrected overall penetration

3. The outlet size distribution is found by using particle diameter and the corrected penetration times the mass fraction ($Pt(d) \times f_i$).

Summarizing these values:

<u>D</u>	<u>Outlet f_i</u>
0.2	4.377×10^{-7}
0.5	1.558×10^{-5}
0.8	2.882×10^{-5}
1.5	9.708×10^{-5}
2.5	4.74×10^{-4}
4.0	5.64×10^{-4}
8.0	1.95×10^{-10}
10.0	2.03×10^{-12}
12.0	1.40×10^{-14}

4. Check to determine if this size distribution is lognormal. First change distribution to cumulative distribution and normalize.

The following results are obtained:

<u>D</u>	<u>Cumulative Outlet f_i</u>	<u>Normalized %</u>
0.2	4.377×10^{-7}	0.037
0.5	1.602×10^{-5}	1.36
0.8	4.484×10^{-5}	3.8
1.5	1.419×10^{-4}	12.03
2.5	6.159×10^{-4}	52.19
4.0	1.180×10^{-3}	100.00
8.0	1.180×10^{-3}	100.00
10.0	1.180×10^{-3}	100.00
12.0	1.180×10^{-3}	100.00

Plot the results on log-probability paper. If the plot is a straight line, use the lognormal opacity program. If not, use the histogram opacity program.

5. In this case, a lognormal distribution is not found (Figure 2).
6. Run histogram opacity program No. 2 using outlet size distribution obtained from ESP program. Do not use cumulative distribution. Since D_{50} 's are used to input particle diameters, the mass fraction f_{i+1} corresponds to D_i of D_{50} .
 - a. Enter card 1; Push 1; enter side one.
 - b. Push A to enter data.

Enter the following data, pressing R/S after each entry.

N250	9.	Number of particle diameters
150	0.2	Particle diameters, μm
150	0.5	
D50	0.8	
D50	1.5	
D50	2.5	
150	4.	
150	8.	
150	10.	
D50	12.	

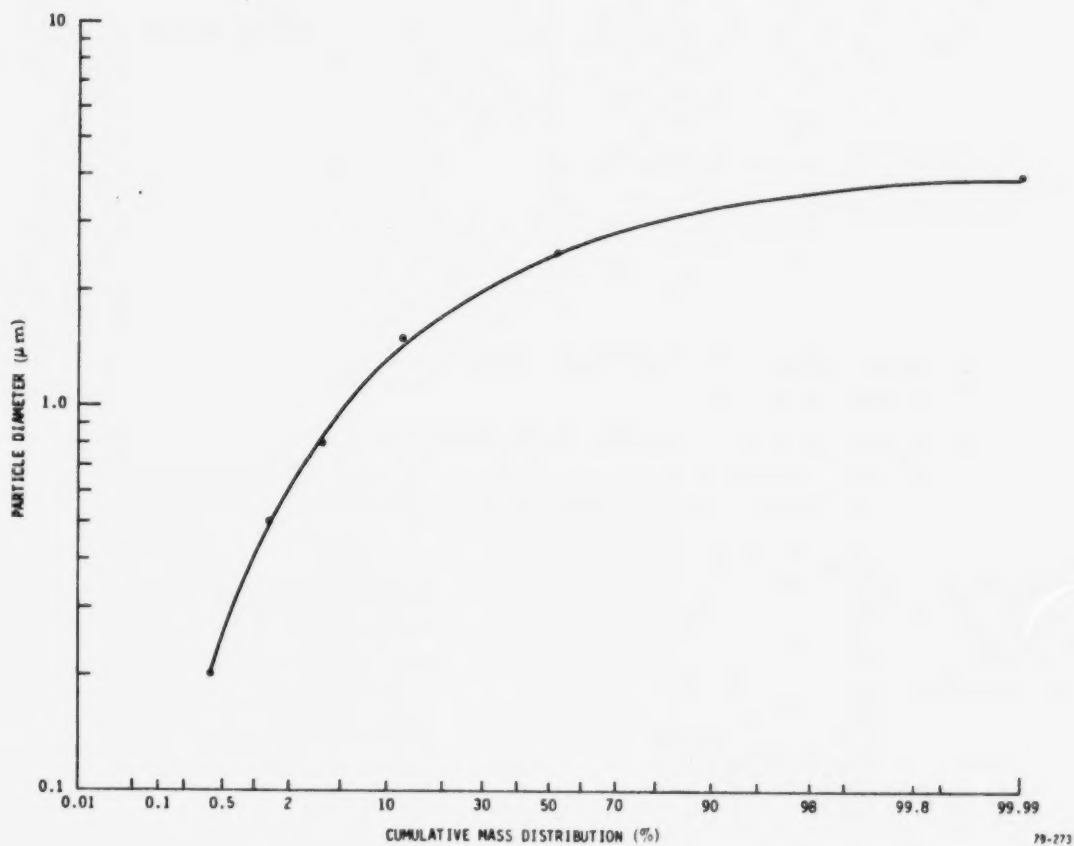


Figure 2. Cumulative particle size distribution plotted on log-probability graph paper.

F	1.558-05	}	Corresponding mass fraction
F	2.882-05		
F	9.708-05		
F	4.74-04		
F	5.64-04		
F	1.95-10		
F	2.03-12		
F	1.4-14		
F	0.00		

- c. Enter card 2 by pushing 1; enter side one. Push 2, enter side two.
- d. Enter card 3 by pushing A (partition automatically set) Push 3, enter side one of card 3. Push R/S to start data entry. Enter data, pressing R/S after each entry.

This step requires approximately 30 minutes after 0.55 is entered.

NEXT CARD

A	1.5	Real part of index of refraction
B	0.002	Imaginary part of index of refraction
W	0.55	Wavelength, μm
2.618259363	=SP	Specific extinction co- efficient, cm^2/m^3
NXT1		

- e. Enter card 4 by pushing 1; enter side one. Push A to start data entry. Enter data, pressing R/S after each entry:

MASS?		Inlet mass concentration
	0.00413	x overall penetration, g/m^3
STACK DIAMETER?		
	7.	
DENSITY?		
	2.4	
3.104694577	=DP%	

The predicted opacity is within 3 percent of desired opacity so that further iterations are not required. However, another iteration is presented for purposes of illustration.

6. Change to standard calculator partition by pushing 6, 2nd, Op, 17.
 - a. Enter card 2 of program No. 6 by pushing 1; enter side one. Push 2; enter side two.
 - b. Enter magnetic card with ESP data stored during Step 2f by pushing 3; enter side one of data card. Push 4; enter side two.
 - c. Press D.
 - d. Press R/S after each entry.
7. Try SCA equal to $162 \text{ m}^2/\text{m}^3/\text{sec}$

SCA	162. $\text{m}^2/\text{m}^3/\text{sec}$	
NP	9.	Number of particle diameters
	0.2 =D	Particle diameter, μm
	6.4	Residence time, sec
7.084817-09		Ideal $\text{Pt}(d) \times f_i$
7.084817-05		Ideal $\text{PT}(d)$
5.8981305-02		Ideal $W(d)$
4.2327131-03		Corrected $\text{Pt}(d)$
4.2327131-07		Corrected $\text{Pt}(d) \times f_i$

5. -01 =D
6.4 00

7.9409228-07
3.9704614-04
4.8342334-02
7.5041802-03
1.500836-05

8. -01 =D
6.4 00

1.2933254-06
3.2333134-04
4.961008-02
6.942388-03
2.7769552-05

1.5 00 =D
6.4 00

2.0147747-06
1.0073874-04
5.6808519-02
4.6888805-03
9.377761-05

2.5 00 =D
6.4 00

2.8435855-06
1.8957236-05
6.7119289-02
3.0713322-03
4.6069982-04

4. 00	=D	Particle diameter, μm
6.4 00		Residence time, sec
5.9511273-07		Ideal $\text{Pt}(d) \times f_i$
2.3804509-06		Ideal $\text{Pt}(d)$
7.9927288-02		Ideal $W(d)$
2.2159553-03		Corrected $\text{Pt}(d)$
5.5398883-04		Corrected $\text{Pt}(d) \times f_i$
8. 00	=D	
6.4 00		
1.4971871-10		
4.2776774-10		
1.3316321-01		
4.2776774-10		
1.4971871-10		
1. 01	=D	
6.4 00		
1.2863926-12		
3.6754074-12		
1.625269-01		
3.6754074-12		
1.2863926-12		
1.2 01	=D	
6.4 00		
9.5295842-15		
3.1765281-14		
1.9185434-01		
3.1765281-14		
9.5295842-15		
7.5481264-06		Ideal overall penetration
1.1516676-03		Corrected overall penetration

8. The new outlet size distribution is summarized as follows:

<u>D</u>	<u>f_i</u>
0.2	4.23×10^{-7}
0.5	1.5×10^{-5}
0.8	2.78×10^{-5}
1.5	9.38×10^{-5}
2.5	4.61×10^{-4}
4.0	5.54×10^{-4}
8.0	1.5×10^{-10}
10.0	1.29×10^{-12}
12.0	9.53×10^{-15}

The outlet mass concentration = inlet mass concentration x overall penetration
 $= (3.5 \text{ g/m}^3) \times 0.00115 = 0.004025$

9. Use histogram opacity program No. 2.

The output is as follows:

a. Enter card 1 by pushing 1; enter side one. Push A to enter data, pressing R/S after each entry.

ND50	9.	Number of particle diameters
D50	0.2	Particle diameters, μm
D50	0.5	
D50	0.8	
D50	1.5	
D50	2.5	
D50	4.	
D50	8.	
D50	10.	
D50	12.	

F	1.5-05	} Corresponding mass fraction
F	2.78-05	
F	9.38-05	
F	4.61-04	
F	5.54-04	
F	1.5-10	
F	1.29-12	
F	9.53-15	
F	0.00	

- b. Enter card 2 by pushing 1; enter side one. Push 2; enter side two.
- c. Enter card 3 by pushing A. Push 3, enter side one of card 3. Push R/S to start data entry. Push R/S after each entry.

NEXT CARD

A	1.5	Real part of index of refraction
B	0.002	Imaginary part of index of refraction
W	0.55	Wavelength
	2.614291852	=SP Specific extinction coefficient
NXT1		

- d. Enter card 4 by pushing 1; enter side one. Push A to start data entry, pressing R/S after each entry.

MASS?		
	0.004025	Inlet mass concentration
STACK DIAMETER?		x overall penetration, g/m ³
	7.	
DENSITY?		
	2.4	
	3.022451889	=DP%

The opacity limitation is 3 percent compared to the opacity using an SCA of $162 \text{ m}^2/\text{m}^3/\text{sec}$, which is 3.02 percent. Further iterations could be performed to obtain closer results by further increasing the SCA.

The individual opacity, scrubber, and ESP programs (including their operation and formulations) are described in Sections 5 and 6.

SECTION 4

IN-STACK OPACITY

BACKGROUND

In-stack opacity refers only to opacity (1-transmittance) as measured by transmissometers in a stack. Out-of-stack plume opacity is much more complex and is beyond the scope of this work. An out-of-stack opacity measurement by observation requires understanding the effect of background contrast, light scattering angles, and gas-to-particle conversion of condensable material, such as SO_3 . Out-of-stack opacity can also be measured by instrumental techniques such as LIDAR and photometry which are less sensitive to environmental factors than observers. When condensables are present, plume opacity may be much greater than the in-stack opacity, because more light is scattered by increased aerosol concentration.

In-stack opacity does not require the out-of-stack opacity parameters to be characterized. In-stack opacity results from almost totally forward light scattering and light absorption removing light from an incident beam. At scattering angles less than 40° , the difference in particle scattering between spherical and irregularly shaped particles is negligible. Thus particle shape is not a factor in in-stack opacity. Also the problems of background contrast and condensables do not apply to in-stack opacity.

DEFINITION

In-stack opacity is defined as 1 minus the transmittance of light using the stack diameter as the path length. It is an accurate way to characterize plume opacity allowing more objective regulatory control. For many years, the visual appearance of plumes has been used to enforce emission from sources using the Ringelmann scale. Over the last 25 years standard smoke sources have been used, permitting training of inspectors to associate the plume-to-background contrast for given conditions to an in-stack transmittance. In-stack opacity as a supplement to human observers was given legal sanction by the 1971 New Source Performance Standards requiring in-stack transmissometers as continuous monitors.

THEORETICAL SUMMARY

The transmission of light through a volume containing an aerosol is described by the Beer-Lambert law:

$$\text{Opacity} = 1 - \text{transmittance} = 1 - I/I_0 = 1 - \exp(-B_E L)$$

where

I is transmitted light

I_0 is incident light

B_E is the light extinction coefficient

L is the illumination path length (generally stack diameter for our case).

Ensor and Pilat (1971) have shown that the aerosol mass concentration is related to optical transmittance through a modified form of the Beer-Lambert law:

$$\frac{I}{I_0} = \exp \frac{-ML Sp}{\rho} \quad (1)$$

where

M is the particle mass concentration

Sp is the ratio of the light extinction coefficient to specific particulate volume (m^2/cm^3)

ρ is the average particle density

The specific extinction coefficient Sp is defined mathematically as

$$Sp = \frac{\frac{3}{2} \int_0^\infty d_p^2 Q(d_p, \lambda, m) n(d_p) d d_p}{\int_0^\infty d_p^3 n(d_p) d d_p} \quad (2)$$

where

d_p is the particle diameter

$Q(d_p, \lambda, m)$ is the light extinction efficiency factor

λ is the wavelength of incident light

m is the aerosol index of refraction

$n(d_p)$ is the number of particle size distribution.

Thus, Sp is defined for a given particle size distribution, particle index of refraction, and wavelength of incident light, and is the indicator of light extinction properties of the aerosol mass.

The light extinction efficiency $Q(d_p, \lambda, m)$ is calculated by using Mie equation for the particle size ranges associated with particulate control devices (0.01 to 40 μm diameters). Expressions for the scattering and extinction efficiencies are obtained by solving Maxwell's equations for the interaction of a plane wave with a homogeneous sphere. The complete derivation is explained by Born and Wolf (1959). The solutions were adapted by Deirmendjian (1969) to computational forms and are easily programmed on the TI-59 calculator. (See Section 5, Mie theory extinction efficiency calculation.) However, the size of this program and numerous iterations result in a very slow calculation of Sp . Fortunately, a good approximation of the Mie series calculation was developed empirically by Deirmendjian based on theoretical work by van de Hulst (1957). (See Section 5, extinction efficiency approximation.) This approximation is used with a Simpson's Rule integration to obtain Sp with the TI-59 calculator. The programs were developed for handling lognormal size distribution data or incremental size data. Using the approximation requires less than an hour to obtain the calculation.

In-stack opacity is calculated by summarizing the above formulations as follows:

$$\text{Opacity (\%)} = \left[1 - \exp \left(-\frac{Sp \cdot ML}{\rho} \right) \right] \times 100 \quad (3)$$

This assumes a constant particle density and index of refraction. Generally a wavelength of incident light of 0.55 μm is used as representative of the maximum photopic response of the human eye.

SECTION 5

DESCRIPTION OF TI-59 OPACITY PROGRAMS

PROGRAM NO. 1: APPROXIMATE OPACITY PROGRAM WITH LOGNORMAL SIZE DISTRIBUTION INPUT

This program computes in-stack opacity for an aerosol mass with a lognormal particle size distribution. The lognormal size distribution is

$$n(d_p) = \frac{1}{\sqrt{2\pi} \ln \sigma_g d_p} \exp \frac{-\ln^2(d_p/d_g)}{2 \ln^2 \sigma_g} \quad (4)$$

where

d_p is the particle diameter

σ_g is the geometric standard deviation

d_g is the geometric mass mean diameter.

It is important that the geometric mass mean diameter be converted to the number mean diameter since the number distribution is required for the integration. This function is substituted into the integral to calculate the specific extinction coefficient (S_p), and the Simpson's Rule (continuous) approximation is applied to obtain the two integral solutions. The integration program is provided by the master library module for all integrations in this report. The extinction efficiency is calculated using Deirmendjian's approximation of the Mie series.

This program can be divided into four basic operations.

1. Data entry

2. 1st Integration

$$= \int_{d_i}^{d_n} d_p^2 n(d_p) d d_p$$

3. 2nd Integration

$$= \int_{d_i}^{d_n} d_p^2 Q n(d_p) d d_p$$

4. Calculation of opacity and specific extinction coefficient

Each integral above is calculated twice at two ranges of particle diameters:

1. $\int_{0.02}^4 \Delta d = 0.199$
2. $\int_4^{40} \Delta d = 1.8$

The two ranges are used to save calculation time and increase accuracy of the program.

Program Operation

Two magnetic cards are required for operation:

1. Enter cards 1 and 2.

- a. Push 1; enter side one of card 1.
- b. Push 2; enter side two of card 1.
- c. Push A; (sets calculator partition).
- d. Push 3; enter side one of card 2.

2. Enter data in following order:

Push R/S to start data entry. Push R/S after each entry.

<u>Data</u>	<u>Register</u>
σ_g - (SIGMA) geometric standard deviation	08
DG - mass mean particle diameter, μm	-
M - particle mass concentration, g/m^3	26
S - stack diameter, m	27
DEN - particle density, g/cm^3	28
W - wavelength of incident light, μm	20
A - real part of refractive index	12
B - imaginary part of refractive index (positive)	13

Results

Directly following printout of B, the following is listed automatically:

1. Increment size (particle radius) of 1st integration
2. O. SD means end of 1st integration at lower range
3. Increment size (particle radius) of 1st integration at upper range
4. Increment size (particle radius) of 2nd integration at lower range
5. O. SD means end of 2nd integration at lower range
6. Increment size (particle radius) of 2nd integration at upper range
7. Sp = specific extinction coefficient
8. OP (%) = in-stack opacity

Sample Calculation

Given: Standard deviation = 2
Mass mean diameter = 1 μm
Wavelength of light = 0.55 μm
Real part of refractive index = 1.5
Imaginary part of refractive index = 0
Mass concentration = 0.01 g/m^3
Particle density = 2.4 g/cm^3
Stack diameter = 6.9 m

Solutions:

<u>Procedure</u>	<u>Enter</u>	<u>Press</u>	<u>Enter</u>	<u>Display</u>	<u>Print</u>
1. Enter card 1		1	Side 1	1	
2. Enter card 1		2	Side 2	2	
3. Enter card 2		A, 3	Side 3	719.29 3	
4. Enter data		R/S		3624223013	SIGMA σ
	σ_g (2)	R/S		2	2
	DG (1.0)	R/S		1622	DG
	M (0.01)	R/S		1.0	1.0
	S (6.9)	R/S		17	M
	DEN (2.4)	R/S		0.01	0.01
	W (0.55)	R/S		37	S
	A (1.5)	R/S		6.9	6.9
	B (0)	R/S		161731	DEN
				2.4	2.4
				43	W
				0.55	0.55
				13	A
				1.5	1.5
				14	B
				0	0
					0.0995
					0 SD
					0.0995
					0.9
					0 SD
					0.9
					4.821892388 = Sp
					12.94494106 = OP %

Summary : Sp = 4.82
In-stack opacity = 12.9 %

Uses

This program can be used to estimate in-stack opacity for a given facility. It can also be used with control device model programs to estimate the design parameters required to meet an opacity limitation. See Sparks (1979) for an example of this use. The effect on particle size distribution

on the specific extinction coefficient and opacity can be examined by varying the value of particle size distribution σ_g and d_g . Also, the effect on opacity of variables such as particle density, stack diameter, and mass grain loading can be examined for a given size distribution.

Another use of the approximate opacity program is to determine the opacity for bimodal lognormal size distributions. The steps for this calculation are:

1. Determine the specific extinction coefficient Sp for each mode, using standard program operation.
2. Clear calculator display.
3. Sum these specific extinction coefficients.
4. Enter the sum from Step 2.
5. Push subroutine 607.

The printed result will show new specific extinction coefficient Sp and in-stack opacity (OP %).

Sample Calculation

Given:

A bimodal distribution

Mode No. 1 standard deviation = 1.5, mass mean diameter = 0.15 μm

Mode No. 2 standard deviation = 3, mass mean diameter = 5.0 μm

Wavelength of light = 0.55 μm

Real part of refraction index = 1.5

Imaginary part of refractive index = 0.0001

Mass concentration = 0.01 g/m^3

Particle density = 2.4 g/cm^3

Stack diameter = 6.9 m

Solution

<u>Procedure</u>	<u>Enter</u>	<u>Press</u>	<u>Enter</u>	<u>Display</u>	<u>Print</u>
1. Enter card 1		1	Side 1	1	
2. Enter card 1		2	Side 2	2	
		A		719.29	
3. Enter card 2		3	Side 3	3	
4. Enter data Mode No. 1		R/S		3624223013	SIGMA
	σ_g (1.5)	R/S	1.5	1.5	1.5
				1622	DG
	DG (0.15)	R/S	0.15	0.15	0.15
				17	M
	M (0.01)	R/S	0.01	0.01	0.01
				37	S
	S (6.9)	R/S	6.9	6.9	6.9
				161731	DEN
	DEN (2.4)	R/S	2.4	2.4	2.4
				43	W
	W (0.55)	R/S	0.55	0.55	0.55
				13	A
	A (1.5)	R/S	1.5	1.5	1.5
					B
	B (0.0001)	R/S	0.0001	0.0001	0.0001
					0.0995
					0 SD
					0.0995
					0.9
					0. SD
					0.9
					3.55483634 = Sp
					9.715243089 = OP %
5. Enter data Mode No. 2		A		719.29	
		R/S		3624223013	SIGMA
	σ_g (3)	R/S	3	3.0	3.0
				1622	DG
	DG (5)	R/S	5	5.0	5.0
				17	M
	M (0.01)	R/S	0.01	0.01	0.01
				37	S
	S (6.9)	R/S	6.9	6.9	6.9
				161731	DEN

<u>Procedure</u>	<u>Enter</u>	<u>Press</u>	<u>Enter</u>	<u>Display</u>	<u>Print</u>
DEN (2.4)		R/S	2.4	2.4	2.4
				13	W
W (0.55)		R/S	0.55	0.55	0.55
				13	A
A (1.5)		R/S	1.5	1.5	1.5
				14	B
B (0.0001)		R/S	0.0001	0.0001	0.0001
					0.0995
					0 SD
					0.0995
					0.9
					0 SD
					0.9
					1.335841986 = Sp
					3.767731879 = OP %

6. Enter sum of SP

Sp (4.89) SBR 607

4.89 = Sp
13.11523626 = OP%

Lognormal Program Caution

This program will produce incorrect results for standard deviation approaching 1.0; i.e., monodisperse aerosols. This logarithm equals zero, and the subsequent division by zero is an undefined operation. The limit for the standard deviation depends upon the geometric mean and the range of particle diameters. Generally, standard deviations greater than 1.009 should provide correct calculations. A flashing display indicates error; however, this is not a serious problem because aerosols found in smoke stacks are not monodisperse.

PROGRAM NO. 2: APPROXIMATE OPACITY PROGRAM WITH HISTOGRAM SIZE DISTRIBUTION INPUT

This program uses the opacity formulation in Section 3 with histogram size data input. Light extinction efficiency is calculated with Deirmendjian's approximation. The advantage of this program is that it allows opacity calculation for aerosol masses with size distributions not conforming to log-normal size distributions. The program is especially designed to handle

cascade impactor data, although any size distribution data in histogram form can be used.

The following manipulations of size distribution are performed:

1. Calculation of the geometric mean diameter X_i

$$X_i = \sqrt{D_{50_{i+1}} \cdot D_{50_i}} \quad (5)$$

where D_{50} is the impactor diameter cut point; i.e., the diameter of particles collected with 50 percent efficiency on that stage

2. Calculation of differential mass distribution Y_i

$$Y_i = \frac{f_i}{\log \left(\frac{D_{50_{i+1}}}{D_{50_i}} \right)} \quad (6)$$

where f_i is the fractional mass loading on impactor stage with cut point D_{50_i}

The values of interpolated points for integration are derived by linear analysis (Figure 3). Points outside the range of experimental values are assumed to reside on a linear extension of the boundary lines as shown by the dashed lines. Negative values of the differential mass distribution do not have physical meaning and are set equal to zero.

This method of finite difference differentiation, although a crude approximation, is the best technique for this program, especially considering the limited number of available program steps. This method also allows a maximum of 10 D_{50} 's to be used, so that the data from a low pressure impactor with 10 stages can be used. The error in this program, generated partly by the finite difference differentiation, is similar to that produced by the lognormal opacity program.

The differential mass distribution is converted to the differential number distribution before the continuous Simpson's Rule integration is applied. The integrals solved in this program are identical to those contained in the lognormal opacity program. This program can also be divided into four basic operations:

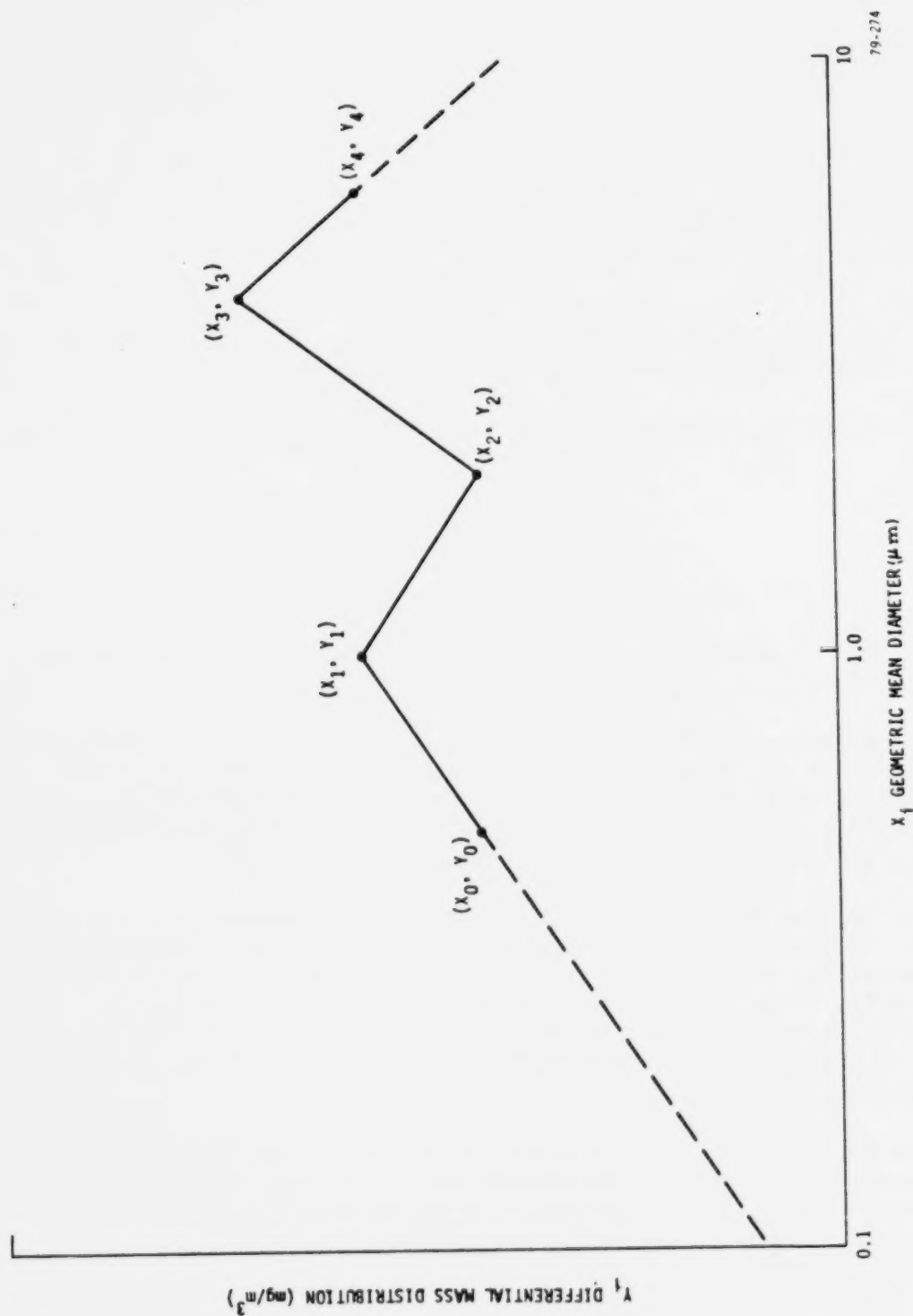


Figure 3. Particle size interpolation procedure used in opacity program.

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1. Data entry

$$2. \text{ 1st integration} = \int_{d_i}^{d_n} d_p^2 Q n(d_p) d d_p$$

$$3. \text{ 2nd integration} = \int_{d_i}^{d_n} d_p^3 n(d_p) d d_p$$

Each of these integrations is performed twice at particle diameter ranges, 0.02 to 2.0 and 2.0 to 40.

4. Calculation of opacity and specific extinction coefficient

Program Operation

Card 1 is used to input the number of D_{50} 's (N D50), the D_{50} 's, and the mass fraction f_i in the range D_{50_i} to $D_{50_{i+1}}$. These D_{50} 's are entered starting with the smallest size cutoff. This part of the program computes the geometric mean diameter (X_i) and the differential mass distribution (Y_i):

Enter card 1.

a. Push I, enter side one of card 1.

b. Push R/S after each entry that will be printed.

ND 50 = number of particle diameter cut points.

D 50 = particle diameter cut point (μm) starting with smallest diameter. (Repeat this step for each particle diameter cut point.)

F = mass fraction in the range D_{50_i} to $D_{50_{i+1}}$. (Repeat this step for the same number of points.)

NEXT CARD = indicates end of this part of program. Proceed to next card.

Cards 2 and 3 are used to compute the integrations. The extinction efficiency using Deirmendjian's approximation is computed for each particle diameter. As described earlier, a linear interpolation of the differential mass distribution is made for each increment of integration. The differential mass distribution must be converted to the differential number distribution for each increment of integration:

1. Enter cards 2 and 3.

- a. Push 1, enter side 1 of card 2.
- b. Push 2, enter side 2 of card 2.
- c. Push A to set partition = 719.29.
- d. Push 3, enter side one of card 3.

2. Enter data.

- a. Push R/S to start data entry.
 - b. Push R/S after each entry which will be printed.
- A = real part of refractive index.
- B = imaginary part of refractive index (positive).
- W = wavelength of incident light.

The number of increments is fixed for a running time of 30 minutes. The fixed ranges of integration for high efficiency control devices are 0.02 to 2 μm and 2 to 40 μm in diameter.

Result

Sp = specific extinction coefficient

NXT 1 = end of this part of program. Proceed to card 4.

Card 4 computes the in-stack opacity (percent after some additional data entry):

1. Enter card 4 - - Push 1, enter side one of card 4
Note: The calculator partition is still equal to 719.29.

2. Enter data.

- a. Push A to start data entry.
- b. Push R/S after card entry that will be printed.

Mass = particle mass concentration, g/m^3
 Stack diameter = stack diameter, m
 Density = density of particles, g/cm^3
 Final result
 OP (%) = in-stack opacity, %

Sample Calculation

Calculate the in-stack opacity for the case of nonlognormal aerosol size distribution.

Given the following data:

Index of refraction = 1.5 (imaginary part equal to zero)
 Wavelength of light = $0.55 \mu\text{m}$
 Mass concentration = 0.01 g/m^3
 Particle density = 2.4 g/cm^3
 Stack diameter = 6.9 m

Cut Point Diameter $D_{50}, \mu\text{m}$	Mass Fraction F_i
0.2	0.0024
0.5	0.0572
0.7	0.09
1.0	0.185
1.5	0.285
2.5	0.219
4.0	0.105
6.0	0.033
8.0	0.018
12.0	0.0048

Solution

<u>Procedure</u>	<u>Press</u>	<u>Enter</u>	<u>Press</u>	<u>Display</u>	<u>Print</u>
Set partition			6, 2nd, Op, 17	479.59	
1. Enter card 1	1	Side one		1	
2. Enter data	A			31160601	ND ₅₀
Note: This part of the program requires 40 seconds after data are input:		ND ₅₀ (1.0)	R/S	160601	10 ⁵⁰
		D ₅₀ (0.2)	R/S		D ₅₀
				160601	0.2
		D ₅₀ (0.5)	R/S		D ₅₀
				160601	0.5
		D ₅₀ (0.7)	R/S		D ₅₀
				160601	0.7
		D ₅₀ (1.0)	R/S		D ₅₀
				160601	1.0
		D ₅₀ (1.5)	R/S		D ₅₀
				160601	1.5
		D ₅₀ (2.5)	R/S		D ₅₀
				160601	2.5
		D ₅₀ (4.0)	R/S		D ₅₀
				160601	4.0
		D ₅₀ (6.0)	R/S		D ₅₀
				160601	6.0
		D ₅₀ (8.0)	R/S		D ₅₀
				160601	8.0
		D ₅₀ (12.0)	R/S		D ₅₀
				160601	12.0
		F(0.0024)	R/S	21	F
					0.0024

<u>Procedure</u>	<u>Press</u>	<u>Enter</u>	<u>Press</u>	<u>Display</u>	<u>Print</u>
		F(0.0572)	R/S	21	F 0.0572
		F(0.09)	R/S	21	F 0.09
		F(0.185)	R/S	21	F 0.185
		F(0.285)	R/S	21	F 0.285
		F(0.219)	R/S	21	F 0.219
		F(0.105)	R/S	21	F 0.105
		F(0.033)	R/S	21	F 0.033
		F(0.018)	R/S	21	F 0.018
		F(0.0048)	R/S	21	F 0.0048
					NEXT CARD
3. Enter card 2	1	Side one		1	
	2	Side two		2	
4. Enter card 3	A			719.29	
	3	Side one		3	
	R/S			13	A
		A(1.5)	R/S		1.5
		B(0.0)	R/S	14	B
					0.0
		W(0.55)	R/S	43	W
					0.55
					3.095120115 = SP
					NXT 1
5. Enter card 4	1	Side one			
	A			3013363671	MASS?
		Mass (0.01)	R/S		0.01
		Stack Diameter (6.9)	R/S		STACK DIAMETER?
					6.9

<u>Procedure</u>	<u>Press</u>	<u>Enter</u>	<u>Press</u>	<u>Display</u>	<u>Print</u>
		Density (2.4)	R/S		DENSITY? 2.4
				8.51404322	= OP%

Uses

The main function of this program is the relatively quick (less than 1 hour) approximate determination of in-stack opacity for size distributions in histogram format. This opacity program can also be used to examine the effect of high efficiency particulate control devices.

In-stack Opacity Program Caution

The calculated specific extinction coefficient (S_p) may not be correct because of the extinction efficiency approximation when a particle index of refraction is not in the following ranges:

$$1.0 \leq \text{real part} \leq 1.5$$

$$0.0 \leq \text{imaginary part} \leq 0.25$$

Table 2 shows that relative errors may vary from 1 to 111 percent for a carbonaceous aerosol ($m = 1.96 - 0.66i$). This table compares the exact S_p derived numerically on a computer to the three opacity programs for various size distributions. Since the errors are a function of the index of refraction, caution is advised if one attempts to extrapolate the approximate programs to aerosols with different light scattering and absorbing properties. Overall, the magnitude of these errors allows only a very rough estimate of in-stack opacity for high absorptive aerosols. If much more accuracy is desired and if the user takes about 8 hours for the calculation, the long opacity program gives very good results. (See Section 5, long opacity calculation.)

COMPARISON OF APPROXIMATE IN-STACK OPACITY PROGRAMS

The two opacity programs are compared in Table 3 for a refractive index equal to 1.5. This table is presented in the same format as Table 2, with the specific extinction coefficient (S_p) data for various size distributions. Only the index of refraction is changed.

TABLE 2. COMPARISON OF APPROXIMATE TI-59
CALCULATIONS OF S_p WITH EXACT VALUES

$$m = 1.96 - 0.66 i \quad \lambda = 0.55 \mu m$$

σ_g	D_g μm	Exact S_p m^2/cm^3	Approximate Calculation (Histogram Size Data) m^2/cm^3	Approximate Calculation (Lognormal Size Data) m^2/cm^3	Long Calculation (Lognormal Size Data) m^2/cm^3
2	1	5.08	5.76	6.63	5.16
4	1	6.05	10.47	10.79	6.15
6	1	6.02	10.61	12.51	6.07
2	2	2.41	2.73	2.35	2.54
4	2	3.88	5.54	6.18	3.90
6	2	4.34	9.17	8.26	4.39
2	3	1.54	1.60	1.42	1.60
4	3	2.83	3.80	4.25	2.89
6	3	3.44	6.06	6.32	3.56
2	4	1.12	1.12	1.02	1.15
4	4	2.22	2.90	3.2	2.31
6	4	2.86	4.18	5.18	3.05

TABLE 3. COMPARISON OF APPROXIMATE TI-59
CALCULATIONS OF S_p WITH EXACT VALUES

$m = 1.5 \quad \lambda = 0.55 \mu m$				
σ_g	D_g	Exact S_p	Approximate (Lognormal Size Data)	Approximate (Histogram Size Data)
	μm	m^2/cm^3	m^2/cm^3	m^2/cm^3
2	1	4.99	4.82	4.92
4	1	3.67	3.73	3.95
6	1	3.06	3.23	3.38
2	2	2.62	2.51	2.99
4	2	2.88	2.87	3.21
6	2	2.62	2.77	2.88
2	3	1.64	1.56	1.91
4	3	2.31	2.316	2.6
6	3	2.27	2.44	2.55
2	4	1.17	1.11	1.31
4	4	1.91	1.94	2.17
6	4	2.0	2.19	2.47

The average relative error for the lognormal size data (opacity program) is 4.1 percent with maximum value of 9.5 percent. The running time for this program is approximately 15 minutes. The greatest contribution to error here is the extinction efficiency approximation. Accuracy cannot be improved by using more increments. However, the opacity from the size distribution σ_g and $D_g = 4$ can be improved by extending the range of integration up to a particle diameter of 80 μm to avoid truncation error.

The average relative error for the incremental size distribution (opacity program) is 12.2 percent with a maximum error of 23.5 percent. The running time for this program is approximately 30 minutes. The primary cause of error arises from using a crude size distribution interpolation. The second major cause of error is the approximation used to calculate the extinction efficiencies.

PROGRAM NO. 3: EXTINCTION EFFICIENCY (Q_{ex}) APPROXIMATION

Since a major part of the specific extinction coefficient calculation depends on calculating the extinction efficiency, it is worthwhile to briefly describe the algorithms used.

Deirmendjian's approximation for the extinction efficiency is based on van de Hulst's (1957) formulation that does not use the exact Mie series calculation. van de Hulst's formula is

$$Q_{\text{ext}}(\rho, m) = 2 - \frac{4 \cos g}{\rho} \exp(-\rho \tan g) \sin(\rho - g) + 4 \left(\frac{\cos g}{\rho} \right)^2 [\cos 2g - \exp(-\rho \tan g) \cos(\rho - 2g)] \quad \text{for } m = a - bi \quad (7)$$

where $\rho = 2x(a-1)$, $x = \frac{\pi d p}{\lambda}$, and $g = \arctan b/(a-1)$; $[m-1] \rightarrow 0$

with

ρ as van de Hulst's normalized size parameter

g as the absorption parameter such that $\rho \tan g$ gives the energy absorbed along the axial ray within the sphere.

Deirmendjian then applied the following correction factors to this original theory with great increase in accuracy:

$$D_1 = \frac{(a-1)^2}{1.632a} [f(g) + 1] + \frac{0.2\rho - a + 1}{(a-1)f(g)}, \rho \leq 5(a-1) \quad (8)$$

$$D_2 = \frac{(a-1)}{8.16a} [f(g)+1] \rho, 5(a-1) < \rho \leq \frac{4.08}{1+3 \tan g} \quad (9)$$

$$D_3 = \frac{(a-1) [f(g) + 1]}{2a (1 + 3 \tan g)}, \frac{4.08}{1 + 3 \tan g} < \rho \leq \frac{4.08}{1 + \tan g} \quad (10)$$

$$D_4 = \frac{2.04(a-1) [f(g)+1]}{a f(g) \rho}, \rho > \frac{4.08}{1+\tan g} \quad (11)$$

where

$$f(g) = 1 + 4 \tan g + 3 \tan^2 g \quad (12)$$

The van de Hulst approximation with $1 + D$ as a correction factor works well for the ranges $1 < a \leq 1.50$ and $0 \leq b \leq 0.25$. Table 4 compares Deirmendjian's approximation with exact Mie values. These discrepancies are the partial cause of the errors previously discussed in S_p calculation.

Program Operation

The extinction efficiency program is operated in accordance with the following procedure:

Enter card 1.

- a. Push 1, enter side one of card 1.
- b. Push 2, enter side two of card 1.
- c. Push A to start data entry.
- d. Push R/S after each entry that will be printed.

A = real part of refractive index register.

B = imaginary part of refractive index register.

TABLE 4. COMPARISON OF DEIRMENDJIAN'S APPROXIMATION
FOR EXTINCTION EFFICIENCY WITH EXACT MIE VALUE

m	$x = \pi dp/\lambda$	Approximate Q_{ext}	Exact Q_{ext}	Relative Error ^a
1.212-0.0601i	1.0	0.193	0.203	4.9
	3.0	1.07	1.08	0.9
	6.0	2.36	2.37	0.004
	10.0	2.72	2.80	2.9
1.29	1.0	0.079	0.072	9.7
	3.0	1.40	1.36	2.9
	6.5	3.78	3.80	0.5
	10.0	2.97	2.81	5.7
	15.0	1.98	1.97	0.5
1.29-0.0472i	2.0	0.767	0.777	1.3
	5.0	2.84	2.83	0.35
	7.0	3.15	3.21	1.9
	12.0	2.17	2.25	3.6
1.315	2.0	0.648	0.642	0.9
	4.0	2.55	2.63	3.0
	6.5	3.93	3.94	0.25
	10.0	2.30	2.45	6.1
1.305-0.0018i	1.0	0.096	0.067	10.3
	3.0	1.56	1.54	1.3
	6.0	3.76	3.78	0.5
	10.0	2.41	2.55	5.5
1.315-0.0143i	2.0	0.717	0.717	0
	4.0	2.53	2.59	2.3
	6.5	3.66	3.72	1.6
	9.0	2.76	2.89	4.5
1.315-0.1370i	2.0	1.22	1.23	0.8
	4.0	2.41	2.41	0
	6.5	2.60	2.71	4.1
	7.0	2.36	2.48	4.8
1.525	1.0	0.322	0.237	36
	2.0	1.76	1.98	11
	4.0	4.23	4.09	3.4
	6.0	2.43	2.52	3.6
	10.0	2.71	2.87	5.6
1.525-0.0682i	1.0	0.576	0.420	37
	2.0	1.99	2.04	2.5
	4.0	3.50	3.61	3.0
	6.0	2.46	2.61	5.7
	10.0	2.35	2.55	7.8

^a Relative Error = $\frac{\text{Exact value} - \text{Approximate value}}{\text{Exact value}}$

Reference: Deirmendjian, 1969.

W = wavelength of incidental radiation

dp = particle diameter

Results

The extinction efficiency Q_{ext} is calculated for aerosol physical and optical characteristics.

Sample Calculation

1. Enter card 1 -- Push 1, enter side one of card 1C

2. Push A

	A?	<u>Press</u>
Enter 1.5	1.5	R/S
	B?	
Enter 0	0	R/S
	W?	
Enter 0.56	0.56	R/S
	D?	
Enter 0.2	0.2	R/S
	0.3831940388	Q_{ext}

Uses

The program for calculating only the extinction efficiency with the approximate formulation allows a quick inspection of the various particle diameters to determine their relative contribution to light scattering.

PROGRAM NO. 4: MIE THEORY EXTINCTION EFFICIENCY CALCULATION PROGRAM

To make an exact calculation of extinction efficiency is time consuming with the TI-59. The extinction efficiency, as derived by van de Hulst (1957) using the cross-section theorem of quantum mechanics, is given by:

$$Q_{\text{ex}}(m, x) = \frac{2}{x^2} \sum_{n=1}^{\infty} (2n+1) \operatorname{Re} \{a_n + b_n\} \quad (13)$$

where

m is the index of refraction

x is the size parameter $\frac{\pi d p}{\lambda}$

a_n and b_n , the Mie coefficients, are functions only of m and x .

Re indicates the real part of the complex expression.

Deirmendjian adapted the Mie coefficients as derived by van de Hulst into a computational form by manipulating Bessel functions to obtain:

$$a_n(m, x) = \frac{\left\{ \left[\frac{A_n(y)}{m} + \frac{n}{x} \right] \text{Re} \{w_n(x)\} - \text{Re} \{w_{n-1}(x)\} \right\}}{\left(\frac{A_n(y)}{m} + \frac{n}{x} \right) w_n(x) - w_{n-1}(x)} \quad (14)$$

$$b_n(m, x) = \frac{\left(m A_n(y) + \frac{n}{x} \right) \text{Re} \{w_n(x)\} - \text{Re} \{w_{n-1}(x)\}}{\left(m A_n(y) + \frac{n}{x} \right) w_n(x) - w_{n-1}(x)} \quad (15)$$

where

$$w_n(x) = \frac{2n-1}{x} w_{n-1}(x) - w_{n-2}(x)$$

$$w_0(x) = \sin x + i \cos x$$

$$w_{-1}(x) = \cos x - i \sin x$$

and

$$A_n(y) = -\frac{n}{y} + \left[\frac{n}{y} - A_{n-1}(y) \right]^{-1} \quad y = mx$$

$$A_0(y) = \frac{\sin p \cos p + i \sinh q \cosh q}{\sin^2 p + \sinh^2 q} \quad \begin{array}{l} p = ax \\ q = bx \end{array}$$

The magnitude of n , the number of terms in the Mie series, determines the time required for calculation. The value of n necessary for accurate evaluation of the extinction efficiency equals $2x$.

The Mie theory calculation is used specifically for particle size with a diameter range from 0.1 to 5 μm for a 0.5 μm wavelength. For $x > 40$, the value of the extinction efficiency equals 2 as determined by geometric and diffractive scattering.

Program Operation

1. Enter card 1D.
 - a. Push 1, enter side one of card 1.
 - b. Push 2, enter side two of card 1.
 - c. Push A.
 - d. Push 3, enter side three of card 2.
2. Press A to start data entry.
3. Press R/S after each entry that will be printed.
4. The data input is identical to the approximate extinction program; i.e., A, B, W, D.

Results

Along with the data printed above, the extinction efficiency is printed.

Sample Calculation

	<u>Enter</u>	<u>Press</u>	<u>Print</u>
1. Enter cards 1 and 2			
	1	enter side one	
	2	enter side two	
	A	Push A	
	3	enter side three	

	<u>Enter</u>	<u>Press</u>	<u>Print</u>
2. Enter data		R/S	
	A(1.5)	R/S	1.5
	B(0)	R/S	0.0
	W(0.56)	R/S	0.56
	D(2.317295971)	R/S	2.317295971

Solution summary: 2.281425896
 Extinction efficiency = 2.28

Uses

If time is not critical, the exact extinction efficiency can be computed to determine the critical sizes for light scattering.

PROGRAM NO. 5: LONG OPACITY CALCULATION USING TI-59 AND LOGNORMAL SIZE DISTRIBUTION

This program uses the exact Mie calculation to obtain the extinction efficiency. The size distribution input is lognormal, and the continuous Simpson's Rule integration is used. This calculation will produce very accurate results with an average error less than 5 percent. The major drawback is the time required for this program -- 8 hours. The program integrates from particle diameter 0.02 to 40 μm using Simpson's Rule for 100 increments. The 100 increments are required for sufficient accuracy especially in the lower end of the particle size range.

Program Operation

Card 1 is used for initial data entry.

Enter card 1.

- Set partition: Press 4, 2nd, Op 17.
- Press 1, enter side one of card 1.
- Press 3, enter side two of card 1.
- Press A to start data entry.

e. Press R/S after each entry which will be printed.

The following data need to be input: SIGMA, DG, W, A, and B.

Card 2 is used to calculate the following integral:

$$\int_{d_0}^{d_n} \frac{d}{d_p} Q_{\text{ext}} n(d_p) d dp$$

This part of the program requires about 8 hours.

Enter card 2.

- a. Push 1, enter side one.
- b. Push 2, enter side two.
- c. Push RST.
- d. Push R/S.

Card 4 is used to calculate the opacity and specific extinction coefficient Sp . The result from Card 1 is divided by the following integral to obtain Sp :

$$\frac{2}{3} \int_{d_0}^{d_n} \frac{d}{d_p}^2 n(d_p) d dp$$

This calculation requires about 4 minutes.

The input data for opacity calculation are also entered with this card.

Enter card 4.

- a. Push 1, enter side one.
- b. Push A to start data entry.

c. Push R/S after each entry which will be printed.

MASS?	Aerosol mass concentration, g/m^3	Register 22
DENS?	Particle density, g/cm^3	Register 23
STCK?	Stack diameter, m	Register 24

Results

The unlabeled output from card 1 is the solution to integral of the extinction efficiency.

The input for card 4 is as follows:

1. Mass concentration (MASS).
2. Aerosol density (DENS).
3. Stack diameter (STCK).

The output for card 4 is

1. Specific extinction coefficient (SP).
2. In-stack opacity (OP %).

All the above are printed automatically.

Sample Calculation

Calculate the in-stack opacity for lognormal size distribution given the following data:

Geometric standard deviation	= 2
Mass median diameter	= $2 \mu\text{m}$
Wavelength of light	= $0.56 \mu\text{m}$
Mass concentration	= 0.01 g/m^3
Particle density	= 2.4 g/cm^3
Stack diameter	= 6.9 m
Index of refraction ($a - bi$)	= $1.96 - 0.66i$

Solution:

<u>Procedure</u>	<u>Press</u>	<u>Enter</u>	<u>Press</u>	<u>Print</u>	<u>Display</u>
1. Set partition		4	2nd OP 17		639.39
2. Enter card 1	1	side one			
3. Enter card 1	3	side two			
4. Enter data			A		
		$\sigma_g(2)$	R/S	SIGMA 2	
		$d_g(2)$	R/S	DG 2	
		W(0.55)	R/S	W 0.55	
		A(1.96)	R/S	A 1.96	
		B(0.66)	R/S	B 0.66	
					639.39
					0.6792158202
5. Enter card 2	1	sides 1			
	2	side 2	RST R/S		
		Enter card 3			
		a. Push 1, enter side one			
		b. Push A to start data entry			
		MASS (0.01)	R/S	MASS ? 0.01	
		DENS (2.4)	R/S	DENS ? 2.4	
		STCK (6.9)	R/S	STCK DIAM? 6.9	
					2.541602496 Sp
					7.0465236 OP (%)

Uses

This program is especially useful for predicting opacity for highly absorptive aerosols with a lognormal particle size distribution. Although the calculation time is much longer, the program accuracy is much greater than the approximate opacity programs (Table 2).

SECTION 6

DESCRIPTION OF TI-59 ELECTROSTATIC PRECIPITATOR AND SCRUBBER PROGRAMS WITH INCREMENTAL SIZE DATA

The theoretical modeling of electrostatic precipitators (ESPs) for computers is fully developed by Gooch, et al. (1975), and for TI-59 programmable calculators by Sparks (1979). EPA publication EPA-600/7-78-026 describes SR-52 calculator programs for ESPs and venturi scrubbers using lognormal size distribution. The TI-59 versions of these programs are in Appendices H and I. The only changes in the venturi scrubber program are (1) Cunningham correction factor and (2) the use of Master Library Simpson Rule integration.

ESP PROGRAM

A new program for ESPs has been developed by Sparks (1979). Because this program is a major improvement in the SR-52 program and has not been reported, a fairly complete discussion of the new TI-59 ESP model is given here.

Recent advances in calculator technology have made available calculators with tremendous computing capability. This computing capability can be used to model electrostatic precipitation without a large computer. This paper describes such a model for the Texas Instruments TI-59 Calculator.

The Model

The ESP model for the TI-59 calculator is based on the EPA/Southern Research Institute (EPA/SoRI) ESP Computer Model Revision I by McDonald (1978). A brief discussion of the theory behind the model and the assumptions in the model are given here. The reader interested in more detail should consult the referenced reports.

Steps in Electrostatic Precipitation Process

The electrostatic precipitation process can be divided into four steps:

1. Corona generation and establishment of electric field.
2. Particle charging.
3. Particle collection.
4. Removal of the collected material.

A complete model of the process would handle all four steps. However, Step 4 is too complex to be modeled at this time and is neglected by both the EPA/SoRI Model and the TI-59 Model. Step 1 is modeled in detail by the EPA/SoRI Model but is neglected in the TI-59 Model. The TI-59 calculator does not have sufficient power to handle the computation used in the computer program. Work is underway to develop approximations for use in the TI-59. When these approximations are developed they will be incorporated into the model. Until then the user must supply the applied voltage and current density as input data.

Particle Charging

Particle charging generally takes place by two mechanisms: field charging and diffusion charging. For large particles, field charging is by far the dominant mechanism. Diffusion charging dominates for very small particles. Particles of major interest in air pollution (those with $0.1 \leq 1.0 \mu\text{m}$) are charged by both mechanisms. Pontius et al (1977) have shown that the following approximation for the charge on a particle agrees with experimental data and detailed theory fairly well.

$$\eta_p = \frac{\pi d}{2} C_1 \left\{ \frac{b d_p / a E_{Av} N t}{b N t + C_1} \right\} \left[1 + 2 \left(\frac{K-1}{K+2} \right) \right] + C_2 T \ln \left(\frac{d_p v N t}{2 C_1 C_2 T} + 1 \right) \quad (16)$$

η_p	= number of charges	E_{Av}	= average electric field
C_1	= $4 \epsilon_0 / e$	T	= absolute temperature
C_2	= k/e	N	= free ion density
ϵ_0	= permittivity of free space	t	= residence time for charging
e	= charge on electron	K	= particle dielectric constant
k	= Boltzman's constant	v	= mean thermal speed of ions
b	= ion mobility	d_p	= particle diameter
		a	= particle radius

The charge on a particle, q , in coulombs is given by

$$q = \eta_p e$$

This equation is used in the TI-59 program and in the approximation procedure in the EPA /SoRI model.

The average electric field used in the calculation is given by

$$E_{Av} = U/H \quad (17)$$

where U = the applied voltage, kV
 H = wire to plate spacing, m

The free ion density, N , is given by

$$N = bE_{Av}/j \quad (18)$$

where b = average ion mobility, $m^2/V\text{-sec}$
 j = current density a/m^2

Particle Collection

Particle collection in an ESP is given by the Deutsch Andersen equation

$$Pt(d_p) = \exp [-\omega(d_p)A/V] \quad (19)$$

where

ωd_p = electrical migration velocity of particles with diameter d_p m/s
 A = collector plate area, m^2
 V = volumetric flow rate of gas, m^3/s

The ratio A/V is called the specific collection area (SCA).

The electrical migration velocity near the collector plate for small particles is given by Stokes' law as

$$\omega(d_p) = q E_p C' / 3\pi\mu d_p \quad (20)$$

where q = the particle charge, coul. ($q = e\eta$)
 E_p = the electric field at the plate, V/m
 C' = the Cunningham correction factor
 $= 1 + 2A \frac{\lambda}{d_p}$
 $A = 1.246 + 0.42 \exp(-0.87 d_p/2\lambda)$
 λ = mean free path of gas, μm
 $= \lambda_o \left(\frac{76}{p}\right) \left(\frac{T}{296.2}\right)$

- λ_o = mean free path at 23°C and 76 cm Hg pressure
 P = barometric pressure, cm Hg
 T = temperature, °K
 μ = viscosity of gas, kg/m-s (10 poise = 1 kg/m-s)

McDonald reported that for an ESP collecting flyash:

$$E_p = E_{Av} / 1.75 \quad (21)$$

This estimate of E_p is used in the TI-59 Model.

McDonald also reported that equation (20) underpredicts the migration velocity for a real ESP. He recommends that the migration velocity be corrected by an empirical factor to improve agreement between predictions and theory. The corrected migration velocity is given by:

$$w(d_p) = w(d_p)_\mu \times (1.7 - 0.45 d_p) \quad (22)$$

where $w(d_p)_\mu$ is the uncorrected migration velocity. Equation (22) applies for $0.2 < d_p \leq 4/5 \mu\text{m}$. Outside this range equation (20) applies.

Non-Ideal Factors

The Deutsch Andersen equation applies to an ideal situation. Certain non-ideal factors exist in real ESPs which result in higher penetrations than those predicted by equation (19). Chief among these non-ideal factors are non-uniform gas flow, sneakage, and reentrainment. Gooch et al. (1975) have shown that the effects of these non-ideal factors can be estimated from:

$$Pt'(d_p) = \exp \left[\frac{-w(d_p)A}{BFV} \right] \quad (23)$$

where $Pt'(d_p)$ = the corrected penetration

B = the correction factor for sneakage and reentrainment

F = the correction factor for non-uniform gas flow

$$B = \frac{\ln P + (d_p)}{N_s \ln [S + (1 - S)Pt(d_p)^{1/N_s}]} \quad (24)$$

N_s = number of baffled sections

S = the fraction of particles that are reentrained and that bypass electrified region per section

$$F = 1 + 0.766 [1 - Pt(d_p)] \sigma^{1.786} + 0.075 \sigma \ln [1/Pt(d_p)] \quad (25)$$

σ = the normalized standard deviation of the gas flow
($\sigma = 0.25$ is generally considered good)

Note that both B and F are particle size dependent.

The overall penetration, Pt_o , is given by:

$$Pt_o = \int_0^{\infty} Pt(d_p) f(d_p) dd_p \quad (26)$$

and the corrected overall penetration, Pt_o' , is given by:

$$Pt_o' = \int_0^{\infty} Pt(d_p)' f(d_p) dd_p \quad (27)$$

where $f(d_p)$ is the fraction of particles with diameters between d and $d + dd$.

TI-59 ESP Model

A mathematical model based on the above equations has been programmed for the Texas Instruments TI-59 Calculator. In the TI-59 model the ESP is divided into user specified time increments. The division of the ESP into time increments is necessary to account for the time dependent nature of the particle charging and particle collection process. For each time increment the calculator calculates particle charge, particle migration velocity, and particle penetration through the increment. All these calculations are performed for each particle diameter in the user specified particle size distribution. The penetration of a given particle diameter through the ESP is given by:

$$Pt(d_p) = \prod_{i=1}^{\eta} Pt(d_p)_i \quad (28)$$

where $Pt(d_p)_i$ = penetration of particles of diameter d_p through the i th increment.

An effective migration velocity for each diameter for the entire ESP is calculated from

$$w(d_p)_e = \frac{-\ln Pt(d_p)}{A/V} \quad (29)$$

The penetration corrected for non-ideal factors $Pt(d_p)'$ is calculated from:

$$Pt(d_p)' = \exp - \left(\frac{w(d_p)_e A/V}{B \times F} \right) \quad (30)$$

These calculations are performed for each of the m particle diameter in the user specified particle size distribution. The overall penetration is given by:

$$Pt_o = \sum_{i=1}^m Pt(d_p)_i f_i \quad (31)$$

and the corrected penetration:

$$Pt_o' = \sum_{i=1}^m Pt(d_p)_i' f_i \quad (32)$$

Conclusion

The TI-59 model provides a useful tool for examining the performance of an ESP. The answers are obtained quickly and without a large expensive computer.

Program Operation for Program No. 6

The first step is to enter the inlet particle size distribution for as many as 16 diameters. Since the histogram opacity program is limited to 10 particle diameters, it is recommended that no more than 10 be used for predicting opacity for an ESP.

Ion speed is calculated from:

$$V = \frac{[(8 \times 8.31 \times 10^7 \times T^\circ K)/(\pi \times 32)]^{1/2}}{100} \quad (33)$$

Ion mobility is calculated from:

$$b = b_r \times \frac{T^\circ K}{273} \times \frac{76}{P} \quad (\text{See Table 5}) \quad (34)$$

1. The particle diameters are stored in Registers 25-39.
2. The mass fractions f_i at diameters d_i are in Registers 41-55.

Card 1 is used to enter all other data.

3. Enter data in following order:

Push A to start data entry. Push R/S after each entry is printed.

ESP	ID - (Any number for identification)	
NP	Number of particle diameters = 15	
NN	Number of time increments (5 to 10)	Register 05
H	Wire to plate spacing (cm)	Register 01
U	Applied voltage (V)	
	The following is printed:	
	Average electric field (V/m) EA	Register 02
	Electric field at plates (V/m) EP	Register 01
V	Ion speed (m/sec)	Register 08
B	Ion mobility ($m^2/V\text{-sec}$)	Register 09
J*	Current density (A/m^2)	
	The following is printed:	
	Ion density	NO
K	Dielectric constant	
T	Temperature ($^\circ C$)	

* J can be estimated from the relationship between J and P given by Hall (see Figure 4).

TABLE 5. REDUCED EFFECTIVE NEGATIVE ION MOBILITIES
FOR VARIOUS GAS COMPOSITIONS

Gas Composition (Volume Percent)					Reduced Effective Ion Mobility (cm ² /V-sec)
<u>N₂</u>	<u>CO₂</u>	<u>O₂</u>	<u>SO₂</u>	<u>H₂O</u>	
				100.0	0.67 ± 0.17
		100.0			2.46 ± 0.06
	100.0				1.08 ± 0.03
			100.0		0.35
			(Laboratory air)		1.03
			(Laboratory air)		1.26 - 1.96
79.4	14.7	4.6	0.2	0.6	5.39
73.5	13.6	4.2	0.2	8.4	2.93
65.9	12.2	3.8	0.2	17.8	2.23
71.0	11.2	3.7	0.0	14.0	2.35
75.7	11.6	3.2	0.0	9.4	3.02
75.1	11.5	3.2	0.1	9.9	2.74
78.5	10.9	3.6	0.0	7.0	3.36
78.3	19.8	3.6	0.1	7.0	2.67
77.9	10.8	3.6	0.3	7.0	2.70
77.6	10.7	3.7	0.7	7.0	2.43

Source: McDonald, J.R. A Mathematical Model of Electrostatic Pre-
cipitation (Revision 1): Volume 1. EPA Report: EPA-600/7-78-
111a. June 1978. p. 75.

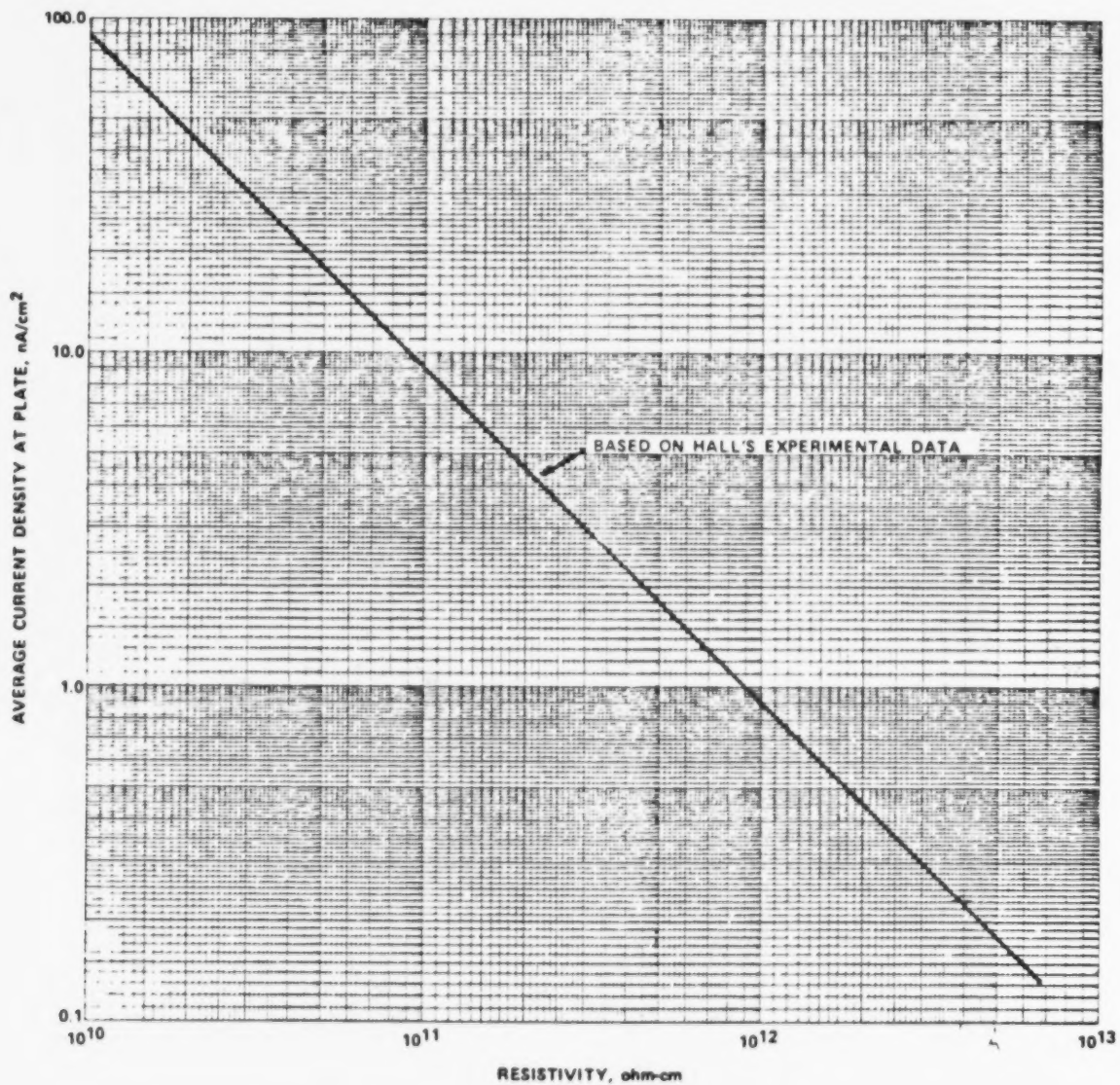


Figure 4. Experimentally determined effect of resistivity on allowable current density in a precipitator (Hall, 1971).

Vis	Viscosity (poise)	Register 04
P	Pressure (cm Hg)	
SCA	Specific collection area ($\text{m}^2/\text{m}^3/\text{sec}$)	Register 03
Length	Length of precipitator (m)	
Vel	Gas velocity (m/sec)	
SIGMA	Normalized standard deviation of gas	Register 06
NS	Number of sections for sneakage	Register 13
S	Fraction of sneakage	Register 14

Card 2 is used to calculate the overall penetration, the outlet size distribution under ideal conditions, the corrected outlet size distribution, ideal migration velocity as a function of diameter, and the ideal and corrected penetrations as a function of diameter.

Press A to obtain above information.

Results

The results for each particle diameter are:

Output	Particle diameter
	$Pt(d_p) \times f_i$ (Penetration x mass fraction)
	Ideal $Pt(d_p)$ (Ideal penetration)
	Ideal $W(d_p)$ (Ideal migration velocity)
	Corrected $Pt(d_p)$ (Corrected penetration)
	Corrected $Pt(d_p) \times f_i$ (Corrected penetration x mass fraction)

After all the particle size data above are printed, the ideal and corrected penetrations follow:

Sample Calculation

Given:

Size distribution	$d_p \mu m$	f_i	
N = 10	0.2	Register 25	0.00033 Register 41
	0.4	Register 26	0.00253 Register 42
	0.7	Register 27	0.0903 Register 43
	1.1	Register 28	0.0815 Register 44
	1.6	Register 29	0.0152 Register 45
	2.5	Register 30	0.03542 Register 46
	3.5	Register 31	0.01652 Register 47
	4.5	Register 32	0.01652 Register 48
	6.0	Register 33	0.01982 Register 49
	8.5	Register 34	0.03304 Register 50

Number of time increments = 5
Wire to plate spacing = 0.1143 cm
Applied voltage = 3.00×10^4 V
Ion speed = 528 m/sec
Ion mobility = 3×10^{-4} m²/V-sec
Current density = 1.3×10^{-4} A/m²
Dielectric constant = 100
Temperature = 150°C
Viscosity = 2.3×10^{-4}
Pressure = 76 cm Hg
SCA = 55 m²/m³/sec
Length of precipitator = 8 m
Gas velocity = 1.25 m/sec
Normalized standard deviation of gas = 0.25
Number of sections for sneakage = 4
Sneakage fraction = 0.1

Solution

<u>Procedure</u>	<u>Press</u>	<u>Enter</u>	<u>Press</u>	<u>Print</u>
Set Partition	6, 2nd, Op, 17			
Enter card 1	1	Side 1		
	2	Side 2		
Enter data			A	
		ESP ID (1)	R/S	1
		NP (10)	R/S	10
		NN (5)	R/S	5
		H (0.1143)	R/S	0.1143
		U (3.0×10^4)	R/S	3. EE 04 2.6246719 05 EA 1.4998125 05 EP
		V (528)	R/S	5.28 02
		B (3×10^{-4})	R/S	3.0 -04
		J (1.3×10^{-4})	R/S	1.3 -04 1.031875 13 NO
		K (100)	R/S	100
		T (150)	R/S	150
		VIS (2.3×10^{-4})	R/S	2.3 -04
		P (76)	R/S	76
		SCA (55)	R/S	55
		Length (8)	R/S	8
		Vel (1.25)	R/S	1.25
		Sigma (0.25)	R/S	0.25
		NS (4)	R/S	4.0
		S (0.1)	R/S	0.1
Enter size data				
Press Trace	0.2		STO 25	
	0.4		STO 26	
	0.7		STO 27	
	1.1		STO 28	

<u>Procedure</u>	<u>Press</u>	<u>Enter</u>	<u>Press</u>	<u>Print</u>
		1.6	STO 29	
		2.5	STO 30	
		3.5	STO 31	
		4.5	STO 32	
		6.0	STO 33	
		8.5	STO 34	
		0.00033	STO 41	
		0.00253	STO 42	
		0.0903	STO 43	
		0.0815	STO 44	
		0.0152	STO 45	
		0.03524	STO 46	
		0.01652	STO 47	
		0.01652	STO 48	
		0.01982	STO 49	
		0.03304	STO 50	

Inactivate Trace

Enter card 2

Side 1
Side 2

A

Particle diameter
Residence time

2.-01 =
6.4 00

Ideal Pt(d) $\times f_i$
Ideal Pt(d)
Ideal W(d)
Corrected Pt(d)
Corrected Pt(d) $\times f_i$

1.2872856-05
3.9008653-02
5.8981305-02
8.4685383-02
2.7946177-05

Print

4. -01 =1
6.4 00

1.6956006-04
6.7019787-02
4.9141335-02
1.2336786-01
3.0959037-04

7. -01 =1
6.4 00

6.1419485-03
6.8016041-02
4.887294-02
1.2366949-01
1.1163743-02

1.1 00 =1
6.4 00

4.5413243-03
5.5130563-03
5.2439303-03
1.0773313-01
6.7802503-03

1.6 00 =1
6.4 00

6.2958231-04
4.1419889-02
5.7890802-02
8.8141568-02
1.3397518-03

2.5 00 =1
6.4 00

8.7864081-04
2.4933054-02
6.7119289-02
6.3229764-02
2.2282169-03

Print

3.5 00 =1
6.4 00

2.5268282-04
1.5295571-02
7.6003491-02
4.6565039-02
7.6925444-04

4.5 00 =1
6.4 00

1.8525515-04
1.1213992-02
8.1647145-02
3.8619206-02
6.3798929-04

6. 00 =1
6.4 00

6.5903855-05
3.3251188-03
1.0375-01
1.9827458-02
3.8901621-04

8.5 00 =1
6.4 00

1.4549037-05
4.4034617-04
1.4050817-01
7.8121544-03
2.5811358-04

Ideal overall penetration
Corrected overall penetration

1.2896609-02
2.5915254-02

Uses

The opacity program can be implemented immediately to determine the effect of an electrostatic precipitator on opacity.

Also, the SCA can be changed to observe its effect on ESP performance. This is performed by entering the inlet size data, then entering card 2 and pressing D.

SCRUBBER PROGRAM WITH INCREMENTAL SIZE DATA

The theory for venturi scrubber computer model has been developed by Yung, et al.(1977), and adapted by Sparks (1978) for SR-52 calculators. Refer to these reports for theoretical derivations and formulations. The SR-52 program presented by Sparks has been written for the TI-59 and a new program for histogram size distribution has been written.

Program No. 7 Operation

1. Enter particle size distribution: diameters in Registers 25-39;
mass fractions in Registers 41-55.
2. Enter card 1
 - a. Push 1, enter side one.
 - b. Push 2, enter side two.
3. Enter data in following order:
 - a. Push A to start data entry.
 - b. Push R/S after each entry that will be printed.

T	Temperature, °C
P	Pressure, cm Hg
F	Factor - f (0.5)
N	Number of particle diameters
L/G	Liquid to gas ratio, m ³ /m ³
UG	Gas velocity, cm/sec

The following is printed:

ΔP Pressure drop, cm H₂O

VIS Viscosity, poise
 RHO L-Liquid density, g/cm³
 RHO P- Particle density, g/cm³

Results

Directly following the printout of RHO, P, the following is listed for each particle diameter:

Particle diameter
 Penetration pt (d_p)
 Outlet concentration

Then, after all diameters are printed the following appear:

Overall penetration
 Overall efficiency

Sample Calculation

Given:

<u>Size Distribution</u>	<u>Diameter, μm</u>	<u>Mass Fraction, f_i</u>
N = 10	0.2	0.00033
	0.4	0.00253
	0.7	0.0903
	1.1	0.0815
	1.6	0.01520
	2.5	0.03524
	3.5	0.01652
	4.5	0.01652
	6.0	0.01982
	8.5	0.03304

Temperature = 65°C
 Pressure = 76 cm Hg
 Factor (f) = 0.5
 Number of particles = 13
 Liquid to gas ratio = $9 \times 10^{-4} \text{ m}^3/\text{m}^3$
 Gas velocity = $6.5 \times 10^3 \text{ cm/sec}$
 Viscosity = $1.8 \times 10^{-4} \text{ poise}$
 Liquid density = 1 g/cm^3
 Particle density = 2.4 g/cm^3

<u>Procedure</u>	<u>Press</u>	<u>Enter</u>	<u>Press</u>	<u>Print</u>
Enter size data				
Press Trace		0.2	STO 25	
		0.4	STO 26	
		0.7	STO 27	
		1.1	STO 28	
		1.6	STO 29	
		2.5	STO 30	
		3.5	STO 31	
		4.5	STO 32	
		6.0	STO 33	
		8.5	STO 34	
		0.00033	STO 41	
		0.00253	STO 42	
		0.0903	STO 43	
		0.0815	STO 44	
		0.0152	STO 45	
		0.03524	STO 46	
		0.01652	STO 47	
		0.01652	STO 48	
		0.01982	STO 49	
		0.03304	STO 50	

Inactivate Trace

Solution

<u>Procedure</u>	<u>Press</u>	<u>Enter</u>	<u>Press</u>	<u>Print</u>
Enter card 1	1	Side 1		
Enter card 1	2	Side 2		

Enter data

	A	
T (65)	R/S	65
P (76)	R/S	76
F (0.5)	R/S	0.5
N (10)	R/S	10
L/G (9×10^{-4})	R/S	9.-04
VG (6.5×10^3)	R/S	6.5 03
VIS (1.8×10^{-4})	R/S	3.13326 01 = ΔP 1.8-04
RHO L (1)	R/S	1.00
RHO P (2.4)	R/S	2.400

Particle diameter, μm

Pt (d_p)

Outlet concentration

2.-01	=I
7.3544066-01	FT
2.4269542-04	=I
4.-01	=I
3.1897058-01	FT
8.0699556-04	=I
7.-01	=I
8.6663485-02	FT
7.8257127-03	=I
1.1 00	=I
2.6899234-02	FT
2.1922876-03	=I
1.6 00	=I
1.1891733-02	FT
1.8075435-04	=I
2.5 00	=I
5.9545995-03	FT
2.0984009-04	=I

Print

3.5 00 =D
4.2499663-03 PT
7.0209443-05 =D

4.5 00 =D
3.5770948-03 PT
5.9093606-05 =D

6. 00 =D
3.1225421-03 PT
6.1888784-05 =D

8.5 00 =D
2.8159444-03 PT
9.3038803-05 =D

Overall penetration
Overall efficiency

1.1742516-02 =DPT
9.8825748-01 =DE

Uses

This program predicts the collection efficiency of a venturi scrubber and also demonstrates the effect of a scrubber on in-stack opacity. The basic input parameters can be changed so that the effect on particle collection and in-stack opacity can be observed.

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van de Hulst, H. C. Light Scattering by Small Particles. John Wiley
and Sons, Inc., New York, NY, 1957.

Yung, S. S., J. Calvert, and H. Barbarika. Venturi Scrubber Performance
Model. EPA-600/2-77-172 (NTIS PB 271-515), A.P.T., Inc., San
Diego, CA, August 1977.

APPENDIX A

Title of Program: PROGRAM NO. 1: Approximate Opacity (Lognormal)

Location	Code	Key	Location	Code	Key
000	76	LBL	035	54	)
001	16	A'	036	92	RTN
002	61	GTD	037	76	LBL
003	03	03	038	19	D'
004	05	05	039	43	RCL
005	92	RTN	040	11	11
006	76	LBL	041	32	X:T
007	17	B'	042	53	(
008	61	GTD	043	05	5
009	03	03	044	65	x
010	46	46	045	43	RCL
011	92	RTN	046	16	16
012	76	LBL	047	54	)
013	18	C'	048	77	GE
014	61	GTD	049	01	01
015	02	02	050	15	15
016	10	10	051	53	(
017	92	RTN	052	04	4
018	76	LBL	053	93	.
019	10	E'	054	00	0
020	53	(	055	08	8
021	01	1	056	55	+
022	85	+	057	53	(
023	04	4	058	01	1
024	65	x	059	85	+
025	43	RCL	060	43	RCL
026	10	10	061	10	10
027	30	TAN	062	30	TAN
028	85	+	063	65	x
029	03	3	064	03	3
030	65	x	065	54	)
031	43	RCL	066	54	)
032	10	10	067	77	GE
033	30	TAN	068	01	01
034	33	X²	069	58	58

Title of Program: Approximate Opacity (Lognormal)

Location	Code	Key	Location	Code	Key
070	53	(	115	53	(
071	04	4	116	43	RCL
072	93	.	117	16	16
073	00	0	118	33	X ²
074	08	8	119	55	+
075	55	+	120	53	(
076	53	(	121	01	1
077	01	1	122	93	.
078	85	+	123	06	6
079	43	RCL	124	03	3
080	10	10	125	02	2
081	30	TAN	126	65	x
082	54	)	127	43	RCL
083	54	)	128	12	12
084	77	GE	129	54	)
085	01	01	130	65	x
086	82	82	131	53	(
087	53	(	132	10	E'
088	53	(	133	85	+
089	02	2	134	01	1
090	93	.	135	54	)
091	00	0	136	85	+
092	04	4	137	53	(
093	65	x	138	93	.
094	43	RCL	139	02	2
095	16	16	140	65	x
096	65	x	141	43	RCL
097	53	(	142	11	11
098	10	E'	143	75	-
099	85	+	144	43	RCL
100	01	1	145	12	12
101	54	)	146	85	+
102	54	)	147	01	1
103	55	+	148	54	)
104	53	(	149	55	+
105	43	RCL	150	53	(
106	12	12	151	43	RCL
107	65	x	152	16	16
108	43	RCL	153	65	x
109	11	11	154	10	E'
110	65	x	155	54	)
111	10	E'	156	54	)
112	54	)	157	92	RTN
113	54	)	158	53	(
114	92	RTN	159	43	RCL

Title of Program: Approximate Opacity (Lognormal)

Location	Code	Key	Location	Code	Key
160	16	16	206	54	)
161	55	+	207	54	)
162	53	(	208	54	)
163	08	8	209	92	RTN
164	93	.	210	53	(
165	01	1	211	53	(
166	06	6	212	02	2
167	65	x	213	75	-
168	43	RCL	214	53	(
169	12	12	215	04	4
170	54	)	216	65	x
171	65	x	217	53	(
172	43	RCL	218	43	RCL
173	11	11	219	10	10
174	65	x	220	39	ODS
175	53	(	221	55	+
176	10	E'	222	43	RCL
177	85	+	223	11	11
178	01	1	224	54	)
179	54	)	225	65	x
180	54	)	226	53	(
181	92	RTN	227	43	RCL
182	53	(	228	11	11
183	43	RCL	229	94	+/-
184	16	16	230	65	x
185	65	x	231	43	RCL
186	53	(	232	10	10
187	10	E'	233	30	TAN
188	85	+	234	54	)
189	01	1	235	22	INV
190	54	)	236	23	LNK
191	55	+	237	65	x
192	53	(	238	53	(
193	02	2	239	43	RCL
194	65	x	240	11	11
195	43	RCL	241	75	-
196	12	12	242	43	RCL
197	65	x	243	10	10
198	53	(	244	54	)
199	01	1	245	38	SIN
200	85	+	246	54	)
201	03	3	247	85	+
202	65	x	248	04	4
203	43	RCL	249	65	x
204	10	10	250	53	(
205	30	TAN	251	43	RCL

Title of Program: Approximate Opacity (Lognormal)

Location	Code	Key	Location	Code	Key
252	10	10	298	85	+
253	39	CDS	299	01	1
254	55	+	300	54	)
255	43	RCL	301	54	)
256	11	11	302	61	GTD
257	54	)	303	00	00
258	33	X ²	304	17	17
259	65	x	305	42	STD
260	53	(	306	06	06
261	53	(	307	87	IFF
262	02	2	308	01	01
263	65	x	309	03	03
264	43	RCL	310	19	19
265	10	10	311	53	(
266	54	)	312	43	RCL
267	39	CDS	313	06	06
268	75	-	314	33	X ²
269	53	(	315	65	x
270	43	RCL	316	17	B'
271	11	11	317	54	)
272	94	+/-	318	92	RTN
273	65	x	319	53	(
274	43	RCL	320	43	RCL
275	10	10	321	06	06
276	30	TAN	322	65	x
277	54	)	323	04	4
278	22	INV	324	65	x
279	23	LNx	325	89	n
280	65	x	326	55	+
281	53	(	327	43	RCL
282	43	RCL	328	20	20
283	11	11	329	65	x
284	75	-	330	43	RCL
285	53	(	331	16	16
286	43	RCL	332	54	)
287	10	10	333	42	STD
288	65	x	334	11	11
289	02	2	335	53	(
290	54	)	336	43	RCL
291	54	)	337	06	06
292	39	CDS	338	65	x
293	54	)	339	17	B'
294	54	)	340	65	x
295	65	x	341	18	C'
296	53	(	342	54	)
297	19	D'	343	61	GTD

Title of Program: Approximate Opacity (Lognormal)

Location	Code	Key	Location	Code	Key
344	00	00	390	03	3
345	05	05	391	69	DP
346	53	(	392	01	01
347	53	(	393	69	DP
348	43	RCL	394	05	05
349	06	06	395	91	R/S
350	55	+	396	99	PRT
351	43	RCL	397	42	STD
352	07	07	398	08	08
353	54	)	399	69	DP
354	23	LN _X	400	00	00
355	33	X ²	401	01	1
356	55	+	402	06	6
357	53	(	403	02	2
358	02	2	404	02	2
359	65	x	405	69	DP
360	43	RCL	406	02	02
361	08	08	407	69	DP
362	23	LN _X	408	05	05
363	33	X ²	409	91	R/S
364	54	)	410	99	PRT
365	54	)	411	55	+
366	94	+/-	412	02	2
367	22	INV	413	95	=
368	23	LN _X	414	23	LN _X
369	61	GTO	415	75	-
370	00	00	416	43	RCL
371	11	11	417	08	08
372	76	LBL	418	23	LN _X
373	11	A	419	33	X ²
374	03	3	420	65	x
375	69	DP	421	03	3
376	17	17	422	95	=
377	91	R/S	423	22	INV
378	70	RAD	424	23	LN _X
379	69	DP	425	42	STD
380	00	00	426	07	07
381	03	3	427	69	DP
382	06	6	428	00	00
383	02	2	429	03	3
384	04	4	430	00	0
385	02	2	431	69	DP
386	02	2	432	02	02
387	03	3	433	69	DP
388	00	0	434	05	05
389	01	1	435	91	R/S

Title of Program: Approximate Opacity (Lognormal)

Location	Code	Key	Location	Code	Key
436	99	PRT	483	69	DP
437	42	STD	484	02	02
438	26	26	485	69	DP
439	69	DP	486	05	05
440	00	00	487	91	R/S
441	03	3	488	99	PRT
442	06	6	489	42	STD
443	69	DP	490	12	12
444	02	02	491	75	-
445	69	DP	492	01	1
446	05	05	493	95	=
447	91	R/S	494	42	STD
448	99	PRT	495	16	16
449	42	STD	496	69	DP
450	27	27	497	00	00
451	69	DP	498	01	1
452	00	00	499	04	4
453	01	1	500	69	DP
454	06	6	501	02	02
455	01	1	502	69	DP
456	07	7	503	05	05
457	03	3	504	91	R/S
458	01	1	505	99	PRT
459	69	DP	506	42	STD
460	02	02	507	13	13
461	69	DP	508	55	+
462	05	05	509	43	RCL
463	91	R/S	510	16	16
464	99	PRT	511	95	=
465	42	STD	512	22	INV
466	28	28	513	30	TAN
467	69	DP	514	42	STD
468	00	00	515	10	10
469	04	4	516	93	.
470	03	3	517	00	0
471	69	DP	518	01	1
472	02	02	519	42	STD
473	69	DP	520	21	21
474	05	05	521	02	2
475	91	R/S	522	42	STD
476	99	PRT	523	22	22
477	42	STD	524	02	2
478	20	20	525	00	0
479	69	DP	526	42	STD
480	00	00	527	23	23
481	01	1	528	00	0
482	03	3	529	42	STD

Title of Program: Approximate Opacity (Lognormal)

Location	Code	Key
530	14	14
531	42	STD
532	15	15
533	02	2
534	42	STD
535	09	09
536	43	RCL
537	21	21
538	15	E
539	43	RCL
540	22	22
541	12	B
542	43	RCL
543	23	23
544	13	C
545	22	INV
546	86	STF
547	01	01
548	36	PGM
549	09	09
550	14	D
551	44	SUM
552	14	14
553	69	DP
554	00	00
555	03	3
556	06	6
557	01	1
558	06	6
559	69	DP
560	04	04
561	25	CLR
562	69	DP
563	06	06
564	86	STF
565	01	01
566	43	RCL
567	21	21
568	15	E
569	43	RCL
570	22	22
571	12	B
572	43	RCL
573	23	23
574	13	C
575	36	PGM

Location	Code	Key
576	09	09
577	14	D
578	44	SUM
579	15	15
580	02	2
581	42	STD
582	21	21
583	02	2
584	00	0
585	42	STD
586	22	22
587	02	2
588	00	0
589	42	STD
590	23	23
591	97	DSZ
592	09	09
593	05	05
594	36	36
595	43	RCL
596	15	15
597	35	1/X
598	65	X
599	43	RCL
600	14	14
601	65	X
602	04	4
603	55	+
604	03	3
605	95	=
606	35	1/X
607	42	STD
608	25	25
609	69	DP
610	00	00
611	06	6
612	04	4
613	03	3
614	06	6
615	03	3
616	03	3
617	69	DP
618	04	04
619	25	CLR
620	43	RCL
621	25	25

Title of Program: Approximate Opacity (Lognormal)

Location	Code	Key	Location	Code	Key
622	69	DP	668	76	LBL
623	06	06	669	15	E
624	43	RCL	670	42	STD
625	25	25	671	01	01
626	65	X	672	92	RTN
627	43	RCL	673	76	LBL
628	26	26	674	12	B
629	65	X	675	42	STD
630	43	RCL	676	02	02
631	27	27	677	92	RTN
632	55	+	678	76	LBL
633	43	RCL	679	13	C
634	28	28	680	42	STD
635	95	=	681	05	05
636	94	+/-	682	35	1/X
637	22	INV	683	65	X
638	23	LN _X	684	53	(
639	94	+/-	685	43	RCL
640	85	+	686	02	02
641	01	1	687	75	-
642	95	=	688	43	RCL
643	65	X	689	01	01
644	01	1	690	54	)
645	00	0	691	95	=
646	00	0	692	99	FRT
647	95	=	693	42	STD
648	42	STD	694	03	03
649	29	29	695	92	RTN
650	69	DP			
651	00	00			
652	06	6			
653	04	4			
654	03	3			
655	02	2			
656	03	3			
657	03	3			
658	06	6			
659	01	1			
660	69	DP			
661	04	04			
662	25	CLR			
663	43	RCL			
664	29	29			
665	69	DP			
666	06	06			
667	91	R			

APPENDIX B

Title of Program: PROGRAM NO. 2: Approximate Opacity (Histogram)
Card 1

Location	Code	Key	Location	Code	Key
000	76	LBL	034	69	DP
001	11	R	035	05	05
002	08	8	036	53	(
003	42	STD	037	91	R/S
004	04	04	038	99	PRT
005	25	CLR	039	65	X
006	69	DP	040	01	1
007	00	00	041	00	0
008	03	3	042	00	0
009	01	1	043	00	0
010	01	1	044	54	)
011	06	6	045	72	ST*
012	00	0	046	04	04
013	06	6	047	01	1
014	00	0	048	44	SUM
015	01	1	049	04	04
016	69	DP	050	97	DS2
017	01	01	051	07	07
018	69	DP	052	00	00
019	05	05	053	34	34
020	91	R/S	054	08	8
021	99	PRT	055	42	STD
022	42	STD	056	04	04
023	06	06	057	43	RCL
024	42	STD	058	06	06
025	07	07	059	42	STD
026	01	1	060	07	07
027	06	6	061	02	2
028	00	0	062	01	1
029	06	6	063	69	DP
030	00	0	064	01	01
031	01	1	065	69	DP
032	69	DP	066	05	05
033	01	01	067	91	R/S

Title of Program: Approximate Opacity (Histogram) Card 1

Location	Code	Key	Location	Code	Key
068	99	PRT	113	04	04
069	74	SN*	114	44	SUM
070	04	04	115	05	05
071	01	1	116	97	DSZ
072	44	SUM	117	07	07
073	04	04	118	00	00
074	97	DSZ	119	96	96
075	07	07	120	53	(
076	00	00	121	43	RCL
077	65	65	122	06	06
078	53	(	123	75	-
079	43	RCL	124	01	1
080	06	06	125	54	)
081	75	-	126	42	STD
082	01	1	127	07	07
083	54	)	128	08	8
084	42	STD	129	42	STD
085	07	07	130	03	03
086	08	8	131	09	9
087	42	STD	132	42	STD
088	04	04	133	04	04
089	09	9	134	01	1
090	42	STD	135	09	9
091	03	03	136	42	STD
092	01	1	137	05	05
093	09	9	138	53	(
094	42	STD	139	53	(
095	05	05	140	73	RC*
096	53	(	141	03	03
097	73	RC*	142	22	INV
098	03	03	143	59	INT
099	59	INT	144	55	+
100	65	x	145	53	(
101	73	RC*	146	73	RC*
102	04	04	147	04	04
103	59	INT	148	59	INT
104	54	)	149	55	+
105	34	FX	150	73	RC*
106	59	INT	151	03	03
107	72	ST*	152	59	INT
108	05	05	153	54	)
109	01	1	154	28	LDG
110	44	SUM	155	54	)
111	03	03	156	55	+
112	44	SUM	157	01	1

Title of Program: Approximate Opacity (Histogram) Card 1

Location	Code	Key	Location	Code	Key
158	00	0	202	01	1
159	54	)	203	01	1
160	74	SM*	204	07	7
161	05	05	205	04	4
162	01	1	206	04	4
163	44	SUM	207	03	3
164	03	03	208	07	7
165	44	SUM	209	69	DP
166	04	04	210	01	01
167	44	SUM	211	01	1
168	05	05	212	05	5
169	97	DSZ	213	01	1
170	07	07	214	03	3
171	01	01	215	03	3
172	38	38	216	05	5
173	53	(	217	01	1
174	43	RCL	218	06	6
175	06	06	219	69	DP
176	75	-	220	02	02
177	01	1	221	69	DP
178	54	)	222	05	05
179	42	STD	223	25	CLR
180	07	07	224	69	DP
181	01	1	225	00	00
182	09	9	226	91	R/S
183	42	STD			
184	05	05			
185	08	8			
186	42	STD			
187	03	03			
188	73	RC*			
189	05	05			
190	72	ST*			
191	03	03			
192	01	1			
193	44	SUM			
194	03	03			
195	44	SUM			
196	05	05			
197	97	DSZ			
198	07	07			
199	01	01			
200	88	88			
201	03	3			

Title of Program: Approximate Opacity (Histogram) Cards 2 and 3

Location	Code	Key	Location	Code	Key
000	76	LBL	045	01	01
001	11	A	046	02	2
002	03	3	047	42	STD
003	69	DP	048	02	02
004	17	17	049	02	2
005	91	R/S	050	00	0
006	01	1	051	36	PGM
007	03	3	052	09	09
008	69	DP	053	13	C
009	01	01	054	36	PGM
010	69	DP	055	09	09
011	05	05	056	14	D
012	91	R/S	057	43	RCL
013	99	PRT	058	04	04
014	42	STD	059	44	SUM
015	23	23	060	17	17
016	01	1	061	86	STF
017	04	4	062	01	01
018	69	DP	063	02	2
019	01	01	064	00	0
020	69	DP	065	42	STD
021	05	05	066	05	05
022	91	R/S	067	36	PGM
023	99	PRT	068	09	09
024	42	STD	069	14	D
025	24	24	070	43	RCL
026	04	4	071	04	04
027	03	3	072	44	SUM
028	69	DP	073	18	18
029	01	01	074	22	INV
030	69	DP	075	86	STF
031	05	05	076	01	01
032	91	R/S	077	02	2
033	99	PRT	078	42	STD
034	42	STD	079	01	01
035	25	25	080	04	4
036	00	0	081	00	0
037	42	STD	082	42	STD
038	17	17	083	02	02
039	42	STD	084	01	1
040	18	18	085	00	0
041	93	.	086	36	PGM
042	00	0	087	09	09
043	02	2	088	13	C
044	42	STD			

Title of Program: Approximate Opacity (Histogram) Cards 2 and 3

Location	Code	Key	Location	Code	Key
089	36	PGM	133	54	)
090	09	09	134	69	DP
091	14	D	135	06	06
092	43	RCL	136	61	GTD
093	04	04	137	07	07
094	44	SUM	138	04	04
095	17	17	139	76	LBL
096	86	STF	140	16	A'
097	01	01	141	53	(
098	01	1	142	42	STD
099	00	0	143	00	00
100	42	STD	144	61	GTD
101	05	05	145	01	01
102	36	PGM	146	58	58
103	09	09	147	43	RCL
104	14	D	148	00	00
105	43	RCL	149	33	X²
106	04	04	150	65	x
107	44	SUM	151	43	RCL
108	18	18	152	20	20
109	22	INV	153	65	x
110	86	STF	154	43	RCL
111	01	01	155	28	28
112	25	CLR	156	54	)
113	69	DP	157	92	RTN
114	00	00	158	53	(
115	06	6	159	43	RCL
116	04	4	160	06	06
117	03	3	161	75	-
118	06	6	162	01	1
119	03	3	163	54	)
120	03	3	164	42	STD
121	69	DP	165	07	07
122	04	04	166	08	8
123	53	(	167	42	STD
124	43	RCL	168	19	19
125	17	17	169	53	(
126	55	+	170	73	RC*
127	43	RCL	171	19	19
128	18	18	172	55	+
129	65	x	173	01	1
130	01	1	174	00	0
131	93	.	175	00	0
132	05	5	176	00	0

Title of Program: Approximate Opacity (Histogram) Cards 2 and 3

Location	Code	Key	Location	Code	Key
177	54	)	222	59	INT
178	32	X:T	223	42	STD
179	43	RCL	224	07	07
180	00	00	225	53	(
181	22	INV	226	73	RC*
182	77	GE	227	19	19
183	01	01	228	59	INT
184	96	96	229	42	STD
185	01	1	230	21	21
186	44	SUM	231	01	1
187	19	19	232	44	SUM
188	97	DSZ	233	19	19
189	07	07	234	53	(
190	01	01	235	73	RC*
191	69	69	236	19	19
192	01	1	237	22	INV
193	22	INV	238	59	INT
194	44	SUM	239	75	-
195	19	19	240	43	RCL
196	53	(	241	07	07
197	43	RCL	242	54	)
198	08	08	243	65	x
199	59	INT	244	01	1
200	55	+	245	00	0
201	01	1	246	55	+
202	00	0	247	53	(
203	00	0	248	73	RC*
204	00	0	249	19	19
205	54	)	250	59	INT
206	32	X:T	251	55	+
207	43	RCL	252	43	RCL
208	00	00	253	21	21
209	22	INV	254	54	)
210	77	GE	255	28	LOG
211	02	02	256	65	x
212	17	17	257	53	(
213	01	1	258	43	RCL
214	22	INV	259	00	00
215	44	SUM	260	55	+
216	19	19	261	43	RCL
217	00	0	262	21	21
218	32	X:T	263	65	x
219	73	RC*	264	01	1
220	19	19	265	00	0
221	22	INV	266	00	0

Title of Program: Approximate Opacity (Histogram) Cards 2 and 3

Location	Code	Key	Location	Code	Key
267	00	0	312	53	(
268	54	)	313	53	(
269	28	LDG	314	43	RCL
270	85	+	315	00	00
271	43	RCL	316	85	+
272	07	07	317	43	RCL
273	65	x	318	03	03
274	01	1	319	54	)
275	00	0	320	55	+
276	54	)	321	43	RCL
277	68	NOP	322	00	00
278	77	GE	323	54	)
279	02	02	324	28	LDG
280	95	95	325	55	+
281	55	+	326	43	RCL
282	01	1	327	03	03
283	25	CLR	328	54	)
284	42	STD	329	42	STD
285	07	07	330	28	28
286	01	1	331	22	INV
287	32	X:T	332	87	IFF
288	43	RCL	333	01	01
289	00	00	334	03	03
290	22	INV	335	43	43
291	77	GE	336	43	RCL
292	02	02	337	00	00
293	97	97	338	42	STD
294	25	CLR	339	20	20
295	42	STD	340	61	GTO
296	07	07	341	01	01
297	53	(	342	47	47
298	53	(	343	70	RAD
299	43	RCL	344	53	(
300	07	07	345	53	(
301	65	x	346	43	RCL
302	06	6	347	00	00
303	55	+	348	65	x
304	89	n	349	03	3
305	55	+	350	55	+
306	43	RCL	351	43	RCL
307	00	00	352	25	25
308	45	YX	353	54	)
309	03	3	354	42	STD
310	54	)	355	26	26
311	65	x			

Title of Program: Approximate Opacity (Histogram) Cards 2 and 3

Location	Code	Key	Location	Code	Key
356	65	x	400	43	RCL
357	02	2	401	23	23
358	65	x	402	75	-
359	53	(	403	01	1
360	43	RCL	404	54	)
361	23	23	405	54	)
362	75	-	406	22	INV
363	01	1	407	77	GE
364	54	)	408	04	04
365	54	)	409	65	65
366	42	STD	410	53	(
367	27	27	411	53	(
368	32	XIT	412	43	RCL
369	53	(	413	23	23
370	53	(	414	75	-
371	43	RCL	415	01	1
372	24	24	416	54	)
373	55	+	417	33	X ²
374	53	(	418	55	+
375	43	RCL	419	01	1
376	23	23	420	93	.
377	75	-	421	06	6
378	01	1	422	03	3
379	54	)	423	02	2
380	54	)	424	55	+
381	42	STD	425	43	RCL
382	29	29	426	23	23
383	33	X ²	427	65	x
384	65	x	428	53	(
385	03	3	429	43	RCL
386	85	+	430	19	19
387	04	4	431	85	+
388	65	x	432	01	1
389	43	RCL	433	54	)
390	29	29	434	85	+
391	85	+	435	53	(
392	01	1	436	93	.
393	54	)	437	02	2
394	42	STD	438	65	x
395	19	19	439	43	RCL
396	53	(	440	27	27
397	05	5	441	75	-
398	65	x	442	43	RCL
399	53	(	443	23	23

Title of Program: Approximate Opacity (Histogram) Cards 2 and 3

Location	Code	Key	Location	Code	Key
444	85	+	489	01	1
445	01	1	490	54	)
446	54	)	491	55	+
447	55	+	492	08	8
448	53	(	493	93	.
449	43	RCL	494	01	1
450	23	23	495	06	6
451	75	-	496	55	+
452	01	1	497	43	RCL
453	54	)	498	23	23
454	55	+	499	65	x
455	43	RCL	500	53	(
456	19	19	501	43	RCL
457	85	+	502	19	19
458	01	1	503	85	+
459	54	)	504	01	1
460	42	STD	505	54	)
461	21	21	506	65	x
462	61	GTD	507	43	RCL
463	06	06	508	27	27
464	03	03	509	85	+
465	53	(	510	01	1
466	04	4	511	54	)
467	93	.	512	42	STD
468	00	0	513	21	21
469	08	8	514	61	GTD
470	55	+	515	06	06
471	53	(	516	03	03
472	01	1	517	53	(
473	85	+	518	04	4
474	03	3	519	93	.
475	65	x	520	00	0
476	43	RCL	521	08	8
477	29	29	522	55	+
478	54	)	523	53	(
479	54	)	524	01	1
480	22	INV	525	85	+
481	77	GE	526	43	RCL
482	05	05	527	29	29
483	17	17	528	54	)
484	53	(	529	54	)
485	53	(	530	22	INV
486	43	RCL	531	77	GE
487	23	23	532	05	05
488	75	-	533	70	70

Title of Program: Approximate Opacity (Histogram) Cards 2 and 3

Location	Code	Key	Location	Code	Key
534	53	(	579	75	-
535	53	(	580	01	1
536	43	RCL	581	54	)
537	23	23	582	65	x
538	75	-	583	53	(
539	01	1	584	43	RCL
540	54	)	585	19	19
541	65	x	586	85	+
542	53	(	587	01	1
543	43	RCL	588	54	)
544	19	19	589	55	+
545	85	+	590	43	RCL
546	01	1	591	23	23
547	54	)	592	55	+
548	55	+	593	43	RCL
549	02	2	594	19	19
550	55	+	595	55	+
551	43	RCL	596	43	RCL
552	23	23	597	27	27
553	55	+	598	85	+
554	53	(	599	01	1
555	01	1	600	54	)
556	85	+	601	42	STD
557	03	3	602	21	21
558	65	x	603	53	(
559	43	RCL	604	53	(
560	29	29	605	02	2
561	54	)	606	75	-
562	85	+	607	53	(
563	01	1	608	04	4
564	54	)	609	65	x
565	42	STD	610	43	RCL
566	21	21	611	29	29
567	61	GTD	612	22	INV
568	06	06	613	30	TAN
569	03	03	614	39	CDS
570	53	(	615	42	STD
571	02	2	616	07	07
572	93	.	617	55	+
573	00	0	618	43	RCL
574	04	4	619	27	27
575	65	x	620	65	x
576	53	(	621	53	(
577	43	RCL	622	43	RCL
578	23	23	623	27	27

Title of Program: Approximate Opacity (Histogram) Cards 2 and 3

Location	Code	Key	Location	Code	Key
624	94	+/-	669	27	27
625	65	x	670	94	+/-
626	43	RCL	671	65	x
627	29	29	672	43	RCL
628	54	)	673	29	29
629	22	INV	674	54	)
630	23	LNx	675	22	INV
631	65	x	676	23	LNx
632	53	(	677	65	x
633	43	RCL	678	53	(
634	27	27	679	43	RCL
635	75	-	680	27	27
636	43	RCL	681	75	-
637	29	29	682	53	(
638	22	INV	683	43	RCL
639	30	TAN	684	29	29
640	54	)	685	22	INV
641	38	SIN	686	30	TAN
642	54	)	687	65	x
643	85	+	688	02	2
644	53	(	689	54	)
645	04	4	690	54	)
646	65	x	691	39	CDS
647	53	(	692	54	)
648	43	RCL	693	54	)
649	07	07	694	54	)
650	55	+	695	65	x
651	43	RCL	696	43	RCL
652	27	27	697	21	21
653	54	)	698	54	)
654	33	X ²	699	42	STD
655	65	x	700	20	20
656	53	(	701	61	GTD
657	53	(	702	01	01
658	43	RCL	703	47	47
659	29	29	704	25	CLR
660	22	INV	705	69	DP
661	30	TAN	706	00	00
662	65	x	707	03	3
663	02	2	708	01	1
664	54	)	709	04	4
665	39	CDS	710	04	4
666	75	-	711	03	3
667	53	(	712	07	7
668	43	RCL	713	00	0

Title of Program: Approximate Opacity (Histogram) Cards 2 and 3

Location	Code	Key
714	02	2
715	69	DP
716	01	01
717	69	DP
718	05	05
719	91	R/S

Title of Program: Approximate Opacity (Histogram) Card 4

Location	Code	Key	Location	Code	Key
000	76	LBL	045	69	DP
001	11	A	046	02	02
002	25	CLR	047	01	1
003	69	DP	048	07	7
004	00	00	049	03	3
005	03	3	050	07	7
006	00	0	051	01	1
007	01	1	052	07	7
008	03	3	053	03	3
009	03	3	054	05	5
010	06	6	055	07	7
011	03	3	056	01	1
012	06	6	057	69	DP
013	07	7	058	03	03
014	01	1	059	69	DP
015	69	DP	060	05	05
016	01	01	061	91	R/S
017	69	DP	062	99	PRT
018	05	05	063	42	STD
019	91	R/S	064	02	02
020	42	STD	065	25	CLR
021	01	01	066	69	DP
022	99	PRT	067	00	00
023	03	3	068	01	1
024	06	6	069	06	6
025	03	3	070	01	1
026	07	7	071	07	7
027	01	1	072	03	3
028	03	3	073	01	1
029	01	1	074	03	3
030	05	5	075	06	6
031	02	2	076	02	2
032	06	6	077	04	4
033	69	DP	078	69	DP
034	01	01	079	01	01
035	00	0	080	03	3
036	00	0	081	07	7
037	01	1	082	04	4
038	06	6	083	05	5
039	02	2	084	07	7
040	04	4	085	01	1
041	01	1	086	00	0
042	03	3	087	00	0
043	03	3	088	00	0
044	00	0	089	00	0

Title of Program: Approximate Opacity (Histogram) Card 4

Location	Code	Key	Location	Code	Key
090	69	DP	135	01	1
091	02	02	136	00	0
092	69	DP	137	00	0
093	05	05	138	95	=
094	91	R/S	139	69	DP
095	99	PRT	140	06	06
096	42	STD	141	91	R/S
097	03	03			
098	06	6			
099	04	4			
100	03	3			
101	02	2			
102	03	3			
103	03	3			
104	06	6			
105	01	1			
106	69	DP			
107	04	04			
108	43	RCL			
109	17	17			
110	55	+			
111	43	RCL			
112	18	18			
113	65	x			
114	01	1			
115	93	.			
116	05	5			
117	65	x			
118	43	RCL			
119	01	01			
120	65	x			
121	43	RCL			
122	02	02			
123	55	+			
124	43	RCL			
125	03	03			
126	95	=			
127	94	+/-			
128	22	INV			
129	23	LNx			
130	94	+/-			
131	85	+			
132	01	1			
133	95	=			
134	65	x			

APPENDIX C

Title of Program: PROGRAM NO. 3: Extinction Efficiency Approximation

Location	Code	Key	Location	Code	Key
000	76	LBL	036	05	05
001	11	A	037	91	R/S
002	25	CLR	038	99	PRT
003	69	DP	039	42	STD
004	00	00	040	08	08
005	01	1	041	01	1
006	03	3	042	06	6
007	07	7	043	07	7
008	01	1	044	01	1
009	69	DP	045	69	DP
010	01	01	046	01	01
011	69	DP	047	69	DP
012	05	05	048	05	05
013	91	R/S	049	91	R/S
014	99	PRT	050	99	PRT
015	42	STD	051	42	STD
016	00	00	052	09	09
017	01	1	053	65	X
018	04	4	054	89	π
019	07	7	055	55	÷
020	01	1	056	43	RCL
021	69	DP	057	08	08
022	01	01	058	95	=
023	69	DP	059	42	STD
024	05	05	060	02	02
025	91	R/S	061	70	RAD
026	99	PRT	062	65	X
027	42	STD	063	02	2
028	01	01	064	65	X
029	04	4	065	53	(
030	03	3	066	43	RCL
031	07	7	067	00	00
032	01	1	068	75	-
033	69	DP	069	01	1
034	01	01	070	54	)
035	69	DP	071	95	=

Title of Program: Extinction Efficiency Approximation

Location	Code	Key	Location	Code	Key
072	42	STD	115	01	1
073	03	03	116	95	=
074	32	X:T	117	33	X ²
075	43	RCL	118	55	÷
076	01	01	119	01	1
077	55	÷	120	93	.
078	53	(	121	06	6
079	43	RCL	122	03	3
080	00	00	123	02	2
081	75	-	124	55	÷
082	01	1	125	43	RCL
083	54	)	126	00	00
084	95	=	127	65	x
085	42	STD	128	53	(
086	04	04	129	43	RCL
087	33	X ²	130	05	05
088	65	x	131	85	+
089	03	3	132	01	1
090	85	+	133	54	)
091	04	4	134	85	+
092	65	x	135	53	(
093	43	RCL	136	93	.
094	04	04	137	02	2
095	85	+	138	65	x
096	01	1	139	43	RCL
097	95	=	140	03	03
098	42	STD	141	75	-
099	05	05	142	43	RCL
100	05	5	143	00	00
101	65	x	144	85	+
102	53	(	145	01	1
103	43	RCL	146	54	)
104	00	00	147	55	÷
105	75	-	148	53	(
106	01	1	149	43	RCL
107	54	)	150	00	00
108	95	=	151	75	-
109	22	INV	152	01	1
110	77	GE	153	54	)
111	45	YX	154	55	÷
112	43	RCL	155	43	RCL
113	00	00	156	05	05
114	75	-	157	85	+

Title of Program: Extinction Efficiency Approximation

Location	Code	Key	Location	Code	Key
158	01	1	203	43	RCL
159	95	=	204	03	03
160	42	STD	205	85	+
161	06	06	206	01	1
162	13	C	207	95	=
163	76	LBL	208	42	STD
164	45	YX	209	06	06
165	04	4	210	13	C
166	93	.	211	76	LBL
167	00	0	212	34	FX
168	08	8	213	04	4
169	55	÷	214	93	.
170	53	(	215	00	0
171	01	1	216	08	8
172	85	+	217	55	÷
173	03	3	218	53	(
174	65	x	219	01	1
175	43	RCL	220	85	+
176	04	04	221	43	RCL
177	54	)	222	04	04
178	95	=	223	54	)
179	22	INV	224	95	=
180	77	GE	225	22	INV
181	34	FX	226	77	GE
182	43	RCL	227	33	X²
183	00	00	228	43	RCL
184	75	-	229	00	00
185	01	1	230	75	-
186	95	=	231	01	1
187	55	÷	232	95	=
188	08	8	233	65	x
189	93	.	234	53	(
190	01	1	235	43	RCL
191	06	6	236	05	05
192	55	÷	237	85	+
193	43	RCL	238	01	1
194	00	00	239	54	)
195	65	x	240	55	÷
196	53	(	241	02	2
197	43	RCL	242	55	÷
198	05	05	243	43	RCL
199	85	+	244	00	00
200	01	1	245	55	÷
201	54	)	246	53	(
202	65	x	247	01	1

Title of Program: Extinction Efficiency Approximation

Location	Code	Key	Location	Code	Key
248	85	+	292	42	STD
249	03	3	293	06	06
250	65	x	294	76	LBL
251	43	RCL	295	13	C
252	04	04	296	02	2
253	54	)	297	75	-
254	85	+	298	53	(
255	01	1	299	04	4
256	95	=	300	65	x
257	42	STD	301	43	RCL
258	06	06	302	04	04
259	13	C	303	22	INV
260	76	LBL	304	30	TAN
261	33	X ²	305	39	CDS
262	02	2	306	42	STD
263	93	.	307	07	07
264	00	0	308	55	÷
265	04	4	309	43	RCL
266	65	x	310	03	03
267	53	(	311	65	x
268	43	RCL	312	53	(
269	00	00	313	43	RCL
270	75	-	314	03	03
271	01	1	315	94	+/-
272	54	)	316	65	x
273	65	x	317	43	RCL
274	53	(	318	04	04
275	43	RCL	319	54	)
276	05	05	320	22	INV
277	85	+	321	23	LNx
278	01	1	322	65	x
279	54	)	323	53	(
280	55	÷	324	43	RCL
281	43	RCL	325	03	03
282	00	00	326	75	-
283	55	÷	327	43	RCL
284	43	RCL	328	04	04
285	05	05	329	22	INV
286	55	÷	330	30	TAN
287	43	RCL	331	54	)
288	03	03	332	38	SIN
289	85	+	333	54	)
290	01	1	334	85	+
291	95	=	335	53	(

Title of Program: Extinction Efficiency Approximation

Location	Code	Key	Location	Code	Key
336	04	4	381	54	)
337	65	x	382	39	CDS
338	53	(	383	54	)
339	43	RCL	384	54	)
340	07	07	385	95	=
341	55	+	386	65	x
342	43	RCL	387	43	RCL
343	03	03	388	06	06
344	54	)	389	95	=
345	33	X ²	390	99	PRT
346	65	x	391	91	R/S
347	53	(			
348	53	(			
349	43	RCL			
350	04	04			
351	22	INV			
352	30	TAN			
353	65	x			
354	02	2			
355	54	)			
356	39	CDS			
357	75	-			
358	53	(			
359	43	RCL			
360	03	03			
361	94	+/-			
362	65	x			
363	43	RCL			
364	04	04			
365	54	)			
366	22	INV			
367	23	LNx			
368	65	x			
369	53	(			
370	43	RCL			
371	03	03			
372	75	-			
373	53	(			
374	43	RCL			
375	04	04			
376	22	INV			
377	30	TAN			
378	65	x			
379	02	2			
380	54	)			

APPENDIX D

Title of Program: PROGRAM NO. 4: Mie Extinction Efficiency, Cards 1 and 2, Banks 1, 2, 3

Location	Code	Key	Location	Code	Key
000	76	LBL	034	05	05
001	11	R	035	91	R/S
002	04	4	036	99	PRT
003	69	DP	037	42	STD
004	17	17	038	09	09
005	91	R/S	039	01	1
006	25	CLR	040	06	6
007	69	DP	041	69	DP
008	00	00	042	01	01
009	01	1	043	69	DP
010	03	3	044	05	05
011	69	DP	045	91	R/S
012	01	01	046	99	PRT
013	69	DP	047	65	X
014	05	05	048	89	#
015	91	R/S	049	55	+
016	99	PRT	050	43	RCL
017	42	STD	051	09	09
018	20	20	052	95	=
019	01	1	053	42	STD
020	04	4	054	05	05
021	69	DP	055	76	LBL
022	01	01	056	34	FX
023	69	DP	057	70	RAD
024	05	05	058	00	0
025	91	R/S	059	42	STD
026	99	PRT	060	16	16
027	42	STD	061	42	STD
028	21	21	062	34	34
029	04	4	063	42	STD
030	03	3	064	06	06
031	69	DP	065	43	RCL
032	01	01	066	09	09
033	69	DP	067	43	RCL

Title of Program: Mie Extinction Efficiency, Cards 1 and 2, Banks 1,2,3

Location	Code	Key	Location	Code	Key
068	05	05	113	06	06
069	65	X	114	02	2
070	01	1	115	65	X
071	93	.	116	43	RCL
072	04	4	117	06	06
073	95	=	118	75	-
074	59	INT	119	01	1
075	42	STD	120	95	=
076	08	08	121	55	+
077	04	4	122	43	RCL
078	32	X!T	123	05	05
079	43	RCL	124	95	=
080	08	08	125	42	STD
081	77	GE	126	12	12
082	10	E'	127	65	X
083	65	X	128	43	RCL
084	02	2	129	07	07
085	95	=	130	95	=
086	42	STD	131	42	STD
087	08	08	132	11	11
088	76	LBL	133	43	RCL
089	10	E'	134	12	12
090	43	RCL	135	65	X
091	05	05	136	43	RCL
092	38	SIN	137	18	18
093	42	STD	138	95	=
094	07	07	139	42	STD
095	43	RCL	140	13	13
096	05	05	141	43	RCL
097	39	CDS	142	11	11
098	42	STD	143	75	-
099	18	18	144	43	RCL
100	42	STD	145	17	17
101	17	17	146	95	=
102	43	RCL	147	42	STD
103	07	07	148	11	11
104	94	+/-	149	43	RCL
105	42	STD	150	13	13
106	10	10	151	75	-
107	76	LBL	152	43	RCL
108	45	YX	153	10	10
109	43	RCL	154	95	=
110	08	08	155	42	STD
111	01	1	156	13	13
112	44	SUM	157	43	RCL

Title of Program: Mie Extinction Efficiency, Cards 1 and 2, Banks 1,2,3

Location	Code	Key
158	07	07
159	42	STD
160	17	17
161	43	RCL
162	18	18
163	42	STD
164	10	10
165	43	RCL
166	11	11
167	42	STD
168	07	07
169	43	RCL
170	13	13
171	42	STD
172	18	18
173	87	IFF
174	00	00
175	44	SUM
176	86	STF
177	00	00
178	43	RCL
179	20	20
180	65	x
181	43	RCL
182	05	05
183	95	=
184	42	STD
185	22	22
186	38	SIN
187	42	STD
188	23	23
189	43	RCL
190	22	22
191	39	CDS
192	65	x
193	43	RCL
194	23	23
195	95	=
196	42	STD
197	24	24
198	43	RCL
199	21	21
200	65	x
201	43	RCL
202	05	05

Location	Code	Key
203	95	=
204	42	STD
205	25	25
206	22	INV
207	23	LNK
208	85	+
209	43	RCL
210	25	25
211	94	+/-
212	22	INV
213	23	LNK
214	95	=
215	55	+
216	02	2
217	95	=
218	42	STD
219	26	26
220	43	RCL
221	25	25
222	22	INV
223	23	LNK
224	75	-
225	43	RCL
226	25	25
227	94	+/-
228	22	INV
229	23	LNK
230	95	=
231	55	+
232	02	2
233	95	=
234	42	STD
235	27	27
236	65	x
237	43	RCL
238	26	26
239	95	=
240	42	STD
241	28	28
242	43	RCL
243	23	23
244	33	X ²
245	85	+
246	43	RCL
247	27	27

Title of Program: Mie Extinction Efficiency, Cards 1 and 2, Banks 1,2,3

Location	Code	Key	Location	Code	Key
248	33	X ²	293	95	=
249	95	=	294	42	STD
250	42	STD	295	12	12
251	29	29	296	43	RCL
252	43	RCL	297	11	11
253	24	24	298	36	PGM
254	55	+	299	04	04
255	43	RCL	300	11	A
256	29	29	301	43	RCL
257	95	=	302	12	12
258	42	STD	303	36	PGM
259	24	24	304	04	04
260	43	RCL	305	11	A
261	28	28	306	43	RCL
262	55	+	307	24	24
263	43	RCL	308	36	PGM
264	29	29	309	04	04
265	95	=	310	16	A'
266	42	STD	311	43	RCL
267	28	28	312	28	28
268	76	LBL	313	36	PGM
269	44	SUM	314	04	04
270	43	RCL	315	16	A'
271	22	22	316	36	PGM
272	36	PGM	317	04	04
273	05	05	318	17	B'
274	11	A	319	36	PGM
275	43	RCL	320	05	05
276	25	25	321	15	E
277	36	PGM	322	43	RCL
278	05	05	323	11	11
279	11	A	324	36	PGM
280	36	PGM	325	04	04
281	05	05	326	16	A'
282	15	E	327	43	RCL
283	65	x	328	12	12
284	43	RCL	329	36	PGM
285	06	06	330	04	04
286	95	=	331	16	A'
287	42	STD	332	36	PGM
288	11	11	333	04	04
289	32	X:T	334	17	B'
290	65	x	335	42	STD
291	43	RCL	336	24	24
292	06	06	337	32	X:T

Title of Program: Mie Extinction Efficiency, Cards 1 and 2, Banks 1,2,3

Location	Code	Key
338	42	STD
339	28	28
340	43	RCL
341	20	20
342	36	PGM
343	04	04
344	16	A'
345	43	RCL
346	21	21
347	94	+/-
348	36	PGM
349	04	04
350	16	A'
351	36	PGM
352	04	04
353	18	C'
354	85	+
355	43	RCL
356	06	06
357	55	+
358	43	RCL
359	05	05
360	95	=
361	42	STD
362	11	11
363	32	X:T
364	42	STD
365	12	12
366	65	x
367	43	RCL
368	07	07
369	95	=
370	42	STD
371	13	13
372	43	RCL
373	11	11
374	65	x
375	43	RCL
376	07	07
377	95	=
378	42	STD
379	19	19
380	75	-
381	43	RCL

Location	Code	Key
382	17	17
383	95	=
384	42	STD
385	19	19
386	43	RCL
387	11	11
388	36	PGM
389	04	04
390	11	A
391	43	RCL
392	12	12
393	36	PGM
394	04	04
395	11	A
396	43	RCL
397	07	07
398	36	PGM
399	04	04
400	16	A'
401	43	RCL
402	18	18
403	36	PGM
404	04	04
405	16	A'
406	36	PGM
407	04	04
408	13	C
409	42	STD
410	11	11
411	32	X:T
412	42	STD
413	12	12
414	43	RCL
415	17	17
416	36	PGM
417	04	04
418	16	A'
419	43	RCL
420	10	10
421	36	PGM
422	04	04
423	16	A'
424	36	PGM
425	04	04

Title of Program: Mie Extinction Efficiency, Cards 1 and 2, Banks 1,2,3

Location	Code	Key
426	17	B'
427	42	STD
428	11	11
429	32	X:T
430	42	STD
431	12	12
432	43	RCL
433	19	19
434	36	PGM
435	04	04
436	11	A
437	43	RCL
438	13	13
439	36	PGM
440	04	04
441	11	A
442	43	RCL
443	11	11
444	36	PGM
445	04	04
446	16	A'
447	43	RCL
448	12	12
449	36	PGM
450	04	04
451	16	A'
452	36	PGM
453	04	04
454	18	C'
455	42	STD
456	11	11
457	75	-
458	93	.
459	05	5
460	95	=
461	33	X ²
462	85	+
463	32	X:T
464	42	STD
465	12	12
466	33	X ²
467	95	=
468	43	RCL
469	24	24
470	36	PGM

Location	Code	Key
471	04	04
472	11	A
473	43	RCL
474	28	28
475	36	PGM
476	04	04
477	11	A
478	43	RCL
479	20	20
480	36	PGM
481	04	04
482	16	A'
483	43	RCL
484	21	21
485	94	+/-
486	36	PGM
487	04	04
488	16	A'
489	36	PGM
490	04	04
491	13	C
492	85	+
493	43	RCL
494	06	06
495	55	+
496	43	RCL
497	05	05
498	95	=
499	42	STD
500	14	14
501	32	X:T
502	42	STD
503	15	15
504	43	RCL
505	14	14
506	65	x
507	43	RCL
508	07	07
509	95	=
510	42	STD
511	13	13
512	43	RCL
513	15	15
514	65	x
515	43	RCL

Title of Program: Mie Extinction Efficiency, Cards 1 and 2, Banks 1,2,3

Location	Code	Key	Location	Code	Key
516	07	07	559	04	04
517	95	=	560	16	A'
518	42	STD	561	43	RCL
519	19	19	562	10	10
520	43	RCL	563	36	PGM
521	13	13	564	04	04
522	75	-	565	16	A'
523	43	RCL	566	36	PGM
524	17	17	567	04	04
525	95	=	568	17	B'
526	42	STD	569	42	STD
527	13	13	570	14	14
528	43	RCL	571	32	X:T
529	14	14	572	42	STD
530	36	PGM	573	15	15
531	04	04	574	43	RCL
532	11	A	575	13	13
533	43	RCL	576	36	PGM
534	15	15	577	04	04
535	36	PGM	578	11	A
536	04	04	579	43	RCL
537	11	A	580	19	19
538	43	RCL	581	36	PGM
539	07	07	582	04	04
540	36	PGM	583	11	A
541	04	04	584	43	RCL
542	16	A'	585	14	14
543	43	RCL	586	36	PGM
544	18	18	587	04	04
545	36	PGM	588	16	A'
546	04	04	589	43	RCL
547	16	A'	590	15	15
548	36	PGM	591	36	PGM
549	04	04	592	04	04
550	13	C	593	16	A'
551	42	STD	594	36	PGM
552	14	14	595	04	04
553	32	X:T	596	18	C'
554	42	STD	597	42	STD
555	15	15	598	14	14
556	43	RCL	599	32	X:T
557	17	17	600	42	STD
558	36	PGM	601	15	15

Title of Program: Mie Extinction Efficiency, Cards 1 and 2, Banks 1,2,3

Location	Code	Key
602	43	RCL
603	11	11
604	85	+
605	43	RCL
606	14	14
607	95	=
608	65	x
609	53	(
610	02	2
611	65	x
612	43	RCL
613	06	06
614	85	+
615	01	1
616	54	)
617	42	STD
618	36	36
619	95	=
620	44	SUM
621	16	16
622	97	DSZ
623	08	08
624	45	YX
625	43	RCL
626	16	16
627	65	x
628	02	2
629	55	+
630	43	RCL
631	05	05
632	33	X ²
633	95	=
634	99	PRT
635	98	ADV
636	22	INV
637	86	STF
638	00	00
639	91	R/S

APPENDIX E

Title of Program: PROGRAM NO. 5: Long Opacity, Card 1, Bank 1

Location	Code	Key	Location	Code	Key
000	76	LBL	036	43	RCL
001	11	A	037	19	19
002	69	DP	038	55	+
003	00	00	039	02	2
004	03	3	040	54	)
005	06	6	041	23	LNK
006	02	2	042	75	-
007	04	4	043	43	RCL
008	02	2	044	39	39
009	02	2	045	23	LNK
010	03	3	046	33	X2
011	00	0	047	65	x
012	01	1	048	03	3
013	03	3	049	54	)
014	69	DP	050	22	INV
015	01	01	051	23	LNK
016	69	DP	052	42	STD
017	05	05	053	38	38
018	91	R/S	054	93	.
019	99	PRT	055	01	1
020	42	STD	056	42	STD
021	39	39	057	01	01
022	01	1	058	42	STD
023	06	6	059	35	35
024	02	2	060	02	2
025	02	2	061	00	0
026	69	DP	062	42	STD
027	01	01	063	02	02
028	69	DP	064	42	STD
029	05	05	065	33	33
030	91	R/S	066	04	4
031	42	STD	067	03	3
032	19	19	068	69	DP
033	99	PRT	069	01	01
034	53	(	070	69	DP
035	53	(	071	05	05

Title of Program: Long Opacity, Card 1, Bank 1

Location	Code	Key
072	91	R/S
073	99	PRT
074	42	STD
075	09	09
076	01	1
077	03	3
078	69	DP
079	01	01
080	69	DP
081	05	05
082	91	R/S
083	99	PRT
084	42	STD
085	20	20
086	01	1
087	04	4
088	69	DP
089	01	01
090	69	DP
091	05	05
092	91	R/S
093	99	PRT
094	42	STD
095	21	21
096	01	1
097	00	0
098	00	0
099	36	PGM
100	09	09
101	13	C
102	42	STD
103	32	32
104	00	0
105	42	STD
106	04	04
107	42	STD
108	31	31
109	04	4
110	69	DP
111	17	17
112	91	R/S

Title of Program: Long Opacity, Card 1, Bank 3

Location	Code	Key	Location	Code	Key
480	85	+	524	43	RCL
481	43	RCL	525	18	18
482	06	06	526	36	PGM
483	55	+	527	04	04
484	43	RCL	528	16	A'
485	34	34	529	36	PGM
486	54	)	530	04	04
487	42	STD	531	13	C
488	14	14	532	42	STD
489	53	(	533	14	14
490	32	X:T	534	32	X:T
491	65	x	535	42	STD
492	43	RCL	536	15	15
493	07	07	537	43	RCL
494	54	)	538	17	17
495	42	STD	539	36	PGM
496	19	19	540	04	04
497	53	(	541	16	A'
498	43	RCL	542	43	RCL
499	14	14	543	10	10
500	65	x	544	36	PGM
501	43	RCL	545	04	04
502	07	07	546	16	A'
503	54	)	547	36	PGM
504	42	STD	548	04	04
505	13	13	549	17	B'
506	53	(	550	42	STD
507	43	RCL	551	14	14
508	13	13	552	32	X:T
509	75	-	553	42	STD
510	43	RCL	554	15	15
511	17	17	555	43	RCL
512	54	)	556	13	13
513	42	STD	557	42	STD
514	13	13	558	01	01
515	43	RCL	559	43	RCL
516	14	14	560	19	19
517	42	STD	561	42	STD
518	01	01	562	02	02
519	43	RCL	563	43	RCL
520	07	07	564	14	14
521	36	PGM	565	36	PGM
522	04	04	566	04	04
523	16	A'	567	16	A'

Title of Program: Long Opacity, Card 1, Bank 3

Location	Code	Key	Location	Code	Key
568	43	RCL	612	43	RCL
569	15	15	613	34	34
570	36	PGM	614	33	X ²
571	04	04	615	54	)
572	16	A'	616	42	STD
573	36	PGM	617	30	30
574	04	04	618	22	INV
575	18	C'	619	86	STF
576	42	STD	620	00	00
577	14	14	621	43	RCL
578	32	XIT	622	35	35
579	42	STD	623	42	STD
580	15	15	624	01	01
581	53	(	625	43	RCL
582	53	(	626	33	33
583	43	RCL	627	42	STD
584	11	11	628	02	02
585	85	+	629	43	RCL
586	43	RCL	630	32	32
587	14	14	631	42	STD
588	54	)	632	03	03
589	65	x	633	43	RCL
590	53	(	634	31	31
591	02	2	635	42	STD
592	65	x	636	04	04
593	43	RCL	637	61	GTD
594	06	06	638	00	00
595	85	+	639	20	20
596	01	1			
597	54	)			
598	42	STD			
599	36	36			
600	54	)			
601	44	SUM			
602	16	16			
603	97	DSZ			
604	08	08			
605	45	YX			
606	53	(			
607	43	RCL			
608	16	16			
609	65	x			
610	02	2			
611	55	+			

Title of Program: Long Opacity, Card 2, Banks 1 and 2

Location	Code	Key	Location	Code	Key
000	36	PGM	045	94	+/-
001	09	09	046	22	INV
002	14	D	047	23	LNK
003	99	PRT	048	54	)
004	91	R/S	049	92	RTN
005	76	LBL	050	76	LBL
006	16	A'	051	10	E'
007	53	(	052	43	RCL
008	42	STD	053	04	04
009	37	37	054	42	STD
010	03	3	055	31	31
011	32	XIT	056	53	(
012	43	RCL	057	43	RCL
013	37	37	058	37	37
014	22	INV	059	65	X
015	77	GE	060	89	#
016	10	E'	061	65	X
017	02	2	062	02	2
018	42	STD	063	55	+
019	30	30	064	43	RCL
020	43	RCL	065	09	09
021	37	37	066	54	)
022	68	NOP	067	42	STD
023	65	X	068	34	34
024	43	RCL	069	76	LBL
025	30	30	070	34	FX
026	65	X	071	70	RAD
027	53	(	072	00	0
028	53	(	073	42	STD
029	43	RCL	074	16	16
030	37	37	075	42	STD
031	55	+	076	06	06
032	43	RCL	077	53	(
033	38	38	078	43	RCL
034	54	)	079	34	34
035	23	LNK	080	65	X
036	33	X ²	081	02	2
037	55	+	082	54	)
038	02	2	083	59	INT
039	55	+	084	42	STD
040	43	RCL	085	08	08
041	39	39	086	43	RCL
042	23	LNK	087	34	34
043	33	X ²	088	38	SIN
044	54	)	089	42	STD

Title of Program: Long Opacity, Card 2, Banks 1 and 2

Location	Code	Key	Location	Code	Key
090	07	07	135	18	18
091	43	RCL	136	54	)
092	34	34	137	42	STD
093	39	CDS	138	13	13
094	42	STD	139	53	(
095	18	18	140	43	RCL
096	42	STD	141	11	11
097	17	17	142	75	-
098	43	RCL	143	43	RCL
099	07	07	144	17	17
100	94	+/-	145	54	)
101	42	STD	146	42	STD
102	10	10	147	11	11
103	76	LBL	148	53	(
104	45	YX	149	43	RCL
105	01	1	150	13	13
106	44	SUM	151	75	-
107	06	06	152	43	RCL
108	53	(	153	10	10
109	53	(	154	54	)
110	53	(	155	42	STD
111	02	2	156	13	13
112	65	x	157	43	RCL
113	43	RCL	158	07	07
114	06	06	159	42	STD
115	75	-	160	17	17
116	01	1	161	43	RCL
117	54	)	162	18	18
118	55	+	163	42	STD
119	43	RCL	164	10	10
120	34	34	165	43	RCL
121	54	)	166	11	11
122	42	STD	167	42	STD
123	12	12	168	07	07
124	65	x	169	43	RCL
125	43	RCL	170	13	13
126	07	07	171	42	STD
127	54	)	172	18	18
128	42	STD	173	87	IFF
129	11	11	174	00	00
130	53	(	175	44	SUM
131	43	RCL	176	86	STF
132	12	12	177	00	00
133	65	x	178	53	(
134	43	RCL	179	43	RCL

Title of Program: Long Opacity, Card 2, Banks 1 and 2

Location	Code	Key	Location	Code	Key
180	20	20	225	53	(
181	65	x	226	53	(
182	43	RCL	227	53	(
183	34	34	228	43	RCL
184	54	)	229	25	25
185	42	STD	230	22	INV
186	22	22	231	23	LNK
187	38	SIN	232	75	-
188	42	STD	233	43	RCL
189	23	23	234	25	25
190	53	(	235	94	+/-
191	43	RCL	236	22	INV
192	22	22	237	23	LNK
193	39	CDS	238	54	)
194	65	x	239	55	+
195	43	RCL	240	02	2
196	23	23	241	54	)
197	54	)	242	42	STD
198	42	STD	243	27	27
199	24	24	244	65	x
200	53	(	245	43	RCL
201	53	(	246	26	26
202	53	(	247	54	)
203	43	RCL	248	42	STD
204	21	21	249	28	28
205	65	x	250	53	(
206	43	RCL	251	43	RCL
207	34	34	252	23	23
208	54	)	253	33	X ²
209	42	STD	254	85	+
210	25	25	255	43	RCL
211	22	INV	256	27	27
212	23	LNK	257	33	X ²
213	85	+	258	54	)
214	43	RCL	259	42	STD
215	25	25	260	29	29
216	94	+/-	261	53	(
217	22	INV	262	43	RCL
218	23	LNK	263	24	24
219	54	)	264	55	+
220	55	+	265	43	RCL
221	02	2	266	29	29
222	54	)	267	54	)
223	42	STD	268	42	STD
224	26	26	269	24	24

Title of Program: Long Opacity, Card 2, Banks 1 and 2

Location	Code	Key	Location	Code	Key
270	53	(	315	28	28
271	43	RCL	316	36	PGM
272	28	28	317	04	04
273	55	+	318	16	A'
274	43	RCL	319	36	PGM
275	29	29	320	04	04
276	54	)	321	17	B'
277	42	STD	322	36	PGM
278	28	28	323	05	05
279	76	LBL	324	15	E
280	44	SUM	325	43	RCL
281	43	RCL	326	11	11
282	22	22	327	36	PGM
283	42	STD	328	04	04
284	01	01	329	16	A'
285	43	RCL	330	43	RCL
286	25	25	331	12	12
287	42	STD	332	36	PGM
288	02	02	333	04	04
289	36	PGM	334	16	A'
290	05	05	335	36	PGM
291	15	E	336	04	04
292	43	RCL	337	17	B'
293	06	06	338	42	STD
294	36	PGM	339	24	24
295	04	04	340	32	X:T
296	16	A'	341	42	STD
297	00	0	342	28	28
298	36	PGM	343	43	RCL
299	04	04	344	20	20
300	16	A'	345	36	PGM
301	36	PGM	346	04	04
302	04	04	347	16	A'
303	13	C	348	43	RCL
304	42	STD	349	21	21
305	11	11	350	94	+/-
306	32	X:T	351	36	PGM
307	42	STD	352	04	04
308	12	12	353	16	A'
309	43	RCL	354	53	(
310	24	24	355	36	PGM
311	36	PGM	356	04	04
312	04	04	357	18	C'
313	16	A'	358	85	+
314	43	RCL			

Title of Program: Long Opacity, Card 2, Banks 1 and 2

Location	Code	Key	Location	Code	Key
359	43	RCL	403	04	04
360	06	06	404	16	A'
361	55	+	405	36	PGM
362	43	RCL	406	04	04
363	34	34	407	13	C
364	54	)	408	42	STD
365	42	STD	409	11	11
366	11	11	410	32	X:T
367	53	(	411	42	STD
368	32	X:T	412	12	12
369	65	x	413	43	RCL
370	43	RCL	414	17	17
371	07	07	415	36	PGM
372	54	)	416	04	04
373	42	STD	417	16	A'
374	13	13	418	43	RCL
375	53	(	419	10	10
376	53	(	420	36	PGM
377	43	RCL	421	04	04
378	11	11	422	16	A'
379	65	x	423	36	PGM
380	43	RCL	424	04	04
381	07	07	425	17	B'
382	54	)	426	42	STD
383	42	STD	427	11	11
384	19	19	428	32	X:T
385	75	-	429	42	STD
386	43	RCL	430	12	12
387	17	17	431	43	RCL
388	54	)	432	19	19
389	42	STD	433	42	STD
390	19	19	434	01	01
391	43	RCL	435	43	RCL
392	11	11	436	13	13
393	42	STD	437	42	STD
394	01	01	438	02	02
395	43	RCL	439	43	RCL
396	07	07	440	11	11
397	36	PGM	441	36	PGM
398	04	04	442	04	04
399	16	A'	443	16	A'
400	43	RCL	444	43	RCL
401	18	18	445	12	12
402	36	PGM	446	36	PGM

Title of Program: Long Opacity, Card 2, Banks 1 and 2

Location	Code	Key
447	04	04
448	16	R'
449	36	PGM
450	04	04
451	18	C'
452	42	STD
453	11	11
454	32	XIT
455	42	STD
456	12	12
457	43	RCL
458	24	24
459	42	STD
460	01	01
461	43	RCL
462	28	28
463	42	STD
464	02	02
465	43	RCL
466	20	20
467	36	PGM
468	04	04
469	16	R'
470	43	RCL
471	21	21
472	94	+/-
473	36	PGM
474	04	04
475	16	R'
476	53	(
477	36	PGM
478	04	04
479	13	C

Title of Program: Long Opacity, Card 3, Bank 1

Location	Code	Key	Location	Code	Key
000	76	LBL	045	01	1
001	11	A	046	05	5
002	25	CLR	047	02	2
003	69	DP	048	06	6
004	00	00	049	00	0
005	03	3	050	00	0
006	00	0	051	69	DP
007	01	1	052	01	01
008	03	3	053	01	1
009	03	3	054	06	6
010	06	6	055	02	2
011	03	3	056	04	4
012	06	6	057	01	1
013	07	7	058	03	3
014	01	1	059	03	3
015	69	DP	060	00	0
016	01	01	061	07	7
017	69	DP	062	01	1
018	05	05	063	69	DP
019	91	R/S	064	02	02
020	99	PRT	065	69	DP
021	42	STD	066	05	05
022	22	22	067	91	R/S
023	01	1	068	99	PRT
024	06	6	069	42	STD
025	01	1	070	24	24
026	07	7	071	25	CLR
027	03	3	072	69	DP
028	01	1	073	00	00
029	03	3	074	01	1
030	06	6	075	00	0
031	07	7	076	00	0
032	01	1	077	36	FGM
033	69	DP	078	09	09
034	01	01	079	13	0
035	69	DP	080	25	CLR
036	05	05	081	69	DP
037	91	R/S	082	00	00
038	99	PRT	083	06	6
039	42	STD	084	04	4
040	23	23	085	00	0
041	03	3	086	00	0
042	06	6	087	02	2
043	03	3	088	06	6
044	07	7	089	03	3

Title of Program: Long Opacity, Card 3, Bank 1

Location	Code	Key	Location	Code	Key
090	06	6	135	23	LNK
091	03	3	136	54	)
092	03	3	137	92	RTN
093	69	DP	138	53	(
094	04	04	139	43	RCL
095	43	RCL	140	08	08
096	04	04	141	55	+
097	42	STD	142	43	RCL
098	08	08	143	04	04
099	00	0	144	65	x
100	42	STD	145	03	3
101	04	04	146	55	+
102	36	PGM	147	04	4
103	09	09	148	54	)
104	14	D	149	42	STD
105	61	GTD	150	09	09
106	01	01	151	69	DP
107	38	38	152	06	06
108	76	LBL	153	06	6
109	16	A'	154	04	4
110	53	(	155	03	3
111	42	STD	156	02	2
112	37	37	157	03	3
113	33	X ²	158	03	3
114	65	x	159	00	0
115	53	(	160	00	0
116	53	(	161	06	6
117	43	RCL	162	01	1
118	37	37	163	69	DP
119	55	+	164	04	04
120	43	RCL	165	53	(
121	38	38	166	53	(
122	54	)	167	53	(
123	23	LNK	168	43	RCL
124	33	X ²	169	22	22
125	55	+	170	65	x
126	02	2	171	43	RCL
127	55	+	172	09	09
128	43	RCL	173	65	x
129	39	39	174	43	RCL
130	23	LNK	175	24	24
131	33	X ²	176	55	+
132	54	)	177	43	RCL
133	94	+/-	178	23	23
134	22	INV	179	54	)

Title of Program: Long Opacity, Card 3, Bank 1

Location	Code	Key
180	94	+/-
181	22	INV
182	23	LNK
183	94	+/-
184	85	+
185	01	1
186	54	)
187	65	x
188	01	1
189	00	0
190	00	0
191	54	)
192	69	DP
193	06	06
194	91	R/S

APPENDIX F

Title of Program: PROGRAM NO. 6: ESP (Histogram) Card 1

Location	Code	Key	Location	Code	Key
000	76	LBL	036	91	R/S
001	11	A	037	99	PRT
002	69	DP	038	42	STD
003	00	00	039	00	00
004	01	1	040	42	STD
005	07	7	041	57	57
006	03	3	042	03	3
007	06	6	043	01	1
008	03	3	044	03	3
009	03	3	045	01	1
010	00	0	046	69	DP
011	00	0	047	01	01
012	69	DP	048	69	DP
013	02	02	049	05	05
014	02	2	050	91	R/S
015	04	4	051	42	STD
016	01	1	052	22	22
017	06	6	053	99	PRT
018	00	0	054	02	2
019	00	0	055	03	3
020	69	DP	056	69	DP
021	03	03	057	01	01
022	69	DP	058	69	DP
023	05	05	059	05	05
024	91	R/S	060	91	R/S
025	99	PRT	061	99	PRT
026	03	3	062	42	STD
027	01	1	063	01	01
028	03	3	064	04	4
029	03	3	065	01	1
030	69	DP	066	69	DP
031	00	00	067	01	01
032	69	DP	068	69	DP
033	01	01	069	05	05
034	69	DP	070	91	R/S
035	05	05	071	99	PRT

Title of Program: ESP (Histogram) Card 1

Location	Code	Key	Location	Code	Key
072	55	+	117	99	PRT
073	43	RCL	118	42	STD
074	01	01	119	09	08
075	95	=	120	01	1
076	42	STD	121	04	4
077	02	02	122	69	DP
078	55	+	123	02	02
079	01	1	124	69	DP
080	93	.	125	05	05
081	07	7	126	91	R/S
082	05	5	127	99	PRT
083	95	=	128	42	STD
084	42	STD	129	09	09
085	01	01	130	69	DP
086	69	DP	131	00	00
087	00	00	132	02	2
088	01	1	133	05	5
089	07	7	134	69	DP
090	01	1	135	01	01
091	03	3	136	69	DP
092	69	DP	137	05	05
093	04	04	138	91	R/S
094	43	RCL	139	99	PRT
095	02	02	140	55	+
096	69	DP	141	01	1
097	06	06	142	93	.
098	01	1	143	06	6
099	07	7	144	52	EE
100	03	3	145	94	+/-
101	03	3	146	01	1
102	69	DP	147	09	9
103	04	04	148	55	+
104	43	RCL	149	43	RCL
105	01	01	150	02	02
106	69	DP	151	55	+
107	06	06	152	43	RCL
108	69	DP	153	09	09
109	00	00	154	95	=
110	04	4	155	42	STD
111	02	2	156	11	11
112	69	DP	157	03	3
113	02	02	158	01	1
114	69	DP	159	03	3
115	05	05	160	02	2
116	91	R/S	161	69	DP

Title of Program: ESP (Histogram) Card 1

Location	Code	Key
162	04	04
163	43	RCL
164	11	11
165	69	DP
166	06	06
167	69	DP
168	00	00
169	02	2
170	06	6
171	69	DP
172	01	01
173	69	DP
174	05	05
175	91	R/S
176	22	INV
177	52	EE
178	99	PRT
179	42	STD
180	12	12
181	03	3
182	07	7
183	69	DP
184	01	01
185	69	DP
186	05	05
187	91	R/S
188	99	PRT
189	65	+
190	02	2
191	07	7
192	03	3
193	95	=
194	42	STD
195	05	05
196	04	4
197	02	2
198	02	2
199	04	4
200	03	3
201	06	6
202	69	DP
203	01	01
204	69	DP
205	05	05
206	91	R/S

Location	Code	Key
207	99	PRT
208	65	x
209	93	.
210	01	1
211	95	=
212	42	STD
213	04	04
214	03	3
215	03	3
216	69	DP
217	01	01
218	69	DP
219	05	05
220	91	R/S
221	22	INV
222	52	EE
223	99	PRT
224	35	1/X
225	65	x
226	07	7
227	06	6
228	65	x
229	93	.
230	00	0
231	06	6
232	05	5
233	03	3
234	65	x
235	43	RCL
236	05	05
237	55	+
238	02	2
239	09	9
240	06	6
241	93	.
242	02	2
243	95	=
244	42	STD
245	07	07
246	03	3
247	06	6
248	01	1
249	05	5
250	01	1
251	03	3

Title of Program: ESP (Histogram) Card 1

Location	Code	Key	Location	Code	Key
252	69	DP	296	02	2
253	01	01	297	07	7
254	69	DP	298	69	DP
255	05	05	299	01	01
256	91	R/S	300	69	DP
257	99	PRT	301	05	05
258	42	STD	302	91	R/S
259	03	03	303	99	PRT
260	02	2	304	35	1/X
261	07	7	305	65	x
262	01	1	306	43	RCL
263	07	7	307	20	20
264	03	3	308	95	=
265	01	1	309	42	STD
266	02	2	310	10	10
267	02	2	311	03	3
268	03	3	312	06	6
269	07	7	313	02	2
270	69	DP	314	04	4
271	01	01	315	02	2
272	02	2	316	02	2
273	03	3	317	03	3
274	00	0	318	00	0
275	00	0	319	01	1
276	00	0	320	03	3
277	00	0	321	69	DP
278	00	0	322	01	01
279	00	0	323	69	DP
280	00	0	324	05	05
281	00	0	325	91	R/S
282	69	DP	326	99	PRT
283	02	02	327	42	STD
284	69	DP	328	06	06
285	05	05	329	03	3
286	91	R/S	330	01	1
287	99	PRT	331	03	3
288	42	STD	332	06	6
289	20	20	333	69	DP
290	69	DP	334	01	01
291	00	00	335	69	DP
292	04	4	336	05	05
293	02	2	337	91	R/S
294	01	1	338	99	PRT
295	07	7	339	42	STD

Title of Program: ESP (Histogram) Card 1

Location	Code	Key	Location	Code	Key
340	13	13	384	21	21
341	03	3	385	91	R/S
342	06	6	386	76	LBL
343	69	DP	387	12	B
344	01	01	388	43	RCL
345	69	DP	389	00	00
346	05	05	390	42	STD
347	91	R/S	391	20	20
348	99	PRT	392	43	RCL
349	42	STD	393	17	17
350	14	14	394	42	STD
351	02	2	395	21	21
352	93	.	396	76	LBL
353	02	2	397	13	C
354	02	2	398	01	1
355	04	4	399	06	6
356	52	EE	400	69	DP
357	08	8	401	01	01
358	42	STD	402	69	DP
359	15	15	403	05	05
360	08	8	404	91	R/S
361	93	.	405	99	PRT
362	06	6	406	72	ST+
363	07	7	407	17	17
364	01	1	408	01	1
365	52	EE	409	44	SUM
366	05	5	410	17	17
367	94	+/-	411	97	DSZ
368	42	STD	412	00	00
369	16	16	413	13	C
370	02	2	414	43	RCL
371	05	5	415	20	20
372	42	STD	416	42	STD
373	17	17	417	00	00
374	04	4	418	43	RCL
375	01	1	419	21	21
376	42	STD	420	42	STD
377	18	18	421	17	17
378	42	STD	422	43	RCL
379	19	19	423	18	18
380	00	0	424	42	STD
381	42	STD	425	21	21
382	20	20	426	76	LBL
383	42	STD	427	14	D

Title of Program: ESP (Histogram) Card 1

Location	Code	Key
428	03	3
429	00	0
430	01	1
431	03	3
432	03	3
433	06	6
434	03	3
435	06	6
436	69	DP
437	01	01
438	69	DP
439	05	05
440	91	R/S
441	99	PRT
442	72	ST*
443	18	18
444	01	1
445	44	SUM
446	18	18
447	97	DSZ
448	00	00
449	14	D
450	43	RCL
451	21	21
452	42	STD
453	18	18
454	43	RCL
455	20	20
456	42	STD
457	00	00
458	00	0
459	42	STD
460	21	21
461	00	0
462	42	STD
463	20	20
464	42	STD
465	21	21
466	91	R/S

Title of Program: ESP (Histogram) Card 2

Location	Code	Key	Location	Code	Key
000	76	LBL	045	89	n
001	12	B	046	65	x
002	01	1	047	73	RC*
003	52	EE	048	17	17
004	94	+/-	049	55	+
005	06	6	050	02	2
006	32	X:T	051	52	EE
007	61	GTD	052	06	6
008	50	IXI	053	65	x
009	76	LBL	054	43	RCL
010	17	B'	055	15	15
011	43	RCL	056	65	x
012	23	23	057	53	(
013	22	INV	058	43	RCL
014	77	GE	059	09	09
015	87	IFF	060	65	x
016	61	GTD	061	73	RC*
017	60	DEG	062	17	17
018	76	LBL	063	55	+
019	10	E'	064	02	2
020	53	(	065	52	EE
021	73	RC*	066	06	6
022	17	17	067	65	x
023	77	GE	068	43	RCL
024	87	IFF	069	02	02
025	23	LNx	070	65	x
026	65	x	071	43	RCL
027	93	.	072	58	58
028	04	4	073	65	x
029	05	5	074	43	RCL
030	94	+/-	075	11	11
031	85	+	076	55	+
032	01	1	077	53	(
033	93	.	078	43	RCL
034	07	7	079	09	09
035	54	)	080	65	x
036	92	RTN	081	43	RCL
037	76	LBL	082	58	58
038	87	IFF	083	65	x
039	01	1	084	43	RCL
040	54	)	085	11	11
041	92	RTN	086	85	+
042	76	LBL	087	43	RCL
043	13	C	088	15	15
044	53	(	089	54	)

Title of Program: ESP (Histogram) Card 2

Location	Code	Key	Location	Code	Key
090	65	x	135	43	RCL
091	53	(	136	15	15
092	01	1	137	65	x
093	85	+	138	43	RCL
094	02	2	139	16	16
095	65	x	140	65	x
096	53	(	141	43	RCL
097	43	RCL	142	05	05
098	12	12	143	54	)
099	75	-	144	85	+
100	01	1	145	01	1
101	54	)	146	54	)
102	55	+	147	23	LNX
103	53	(	148	54	)
104	43	RCL	149	54	)
105	12	12	150	92	RTN
106	85	+	151	76	LBL
107	02	2	152	18	C'
108	54	)	153	53	(
109	54	)	154	01	1
110	85	+	155	85	+
111	43	RCL	156	02	2
112	16	16	157	65	x
113	65	x	158	43	RCL
114	43	RCL	159	07	07
115	05	05	160	55	+
116	65	x	161	73	RC*
117	53	(	162	17	17
118	73	RC*	163	65	x
119	17	17	164	53	(
120	55	+	165	01	1
121	02	2	166	93	.
122	52	EE	167	02	2
123	06	6	168	06	6
124	65	x	169	85	+
125	43	RCL	170	93	.
126	58	58	171	04	4
127	65	x	172	02	2
128	43	RCL	173	65	x
129	11	11	174	53	(
130	65	x	175	01	1
131	43	RCL	176	93	.
132	08	08	177	00	0
133	55	+	178	08	8
134	53	(	179	65	x

Title of Program: ESP (Histogram) Card 2

Location	Code	Key	Location	Code	Key
180	73	RC*	225	22	22
181	17	17	226	95	=
182	55	+	227	42	STD
183	53	(	228	59	59
184	02	2	229	42	STD
185	65	x	230	58	58
186	43	RCL	231	01	1
187	07	07	232	42	STD
188	54	)	233	23	23
189	54	)	234	76	LBL
190	94	+/-	235	30	TAN
191	22	INV	236	43	RCL
192	23	LNx	237	58	58
193	54	)	238	13	C
194	54	)	239	65	x
195	24	CE	240	01	1
196	92	RTN	241	93	.
197	76	LBL	242	06	6
198	11	A	243	52	EE
199	04	4	244	01	1
200	93	.	245	09	9
201	05	5	246	94	+/-
202	32	X:T	247	65	x
203	98	ADV	248	43	RCL
204	69	DP	249	01	01
205	00	00	250	55	+
206	06	6	251	53	(
207	04	4	252	06	6
208	01	1	253	65	x
209	06	6	254	89	#
210	69	DP	255	65	x
211	04	04	256	53	(
212	73	RC*	257	73	RC*
213	17	17	258	17	17
214	69	DP	259	55	+
215	06	06	260	02	2
216	43	RCL	261	52	EE
217	22	22	262	06	6
218	42	STD	263	54	)
219	24	24	264	65	x
220	43	RCL	265	43	RCL
221	10	10	266	04	04
222	99	PRT	267	54	)
223	55	+	268	65	x
224	43	RCL	269	18	C'

Title of Program: ESP (Histogram) Card 2

Location	Code	Key	Location	Code	Key
270	65	x	315	12	B
271	10	E'	316	65	x
272	95	=	317	17	B'
273	65	x	318	54	)
274	43	RCL	319	65	x
275	03	03	320	43	RCL
276	55	+	321	03	03
277	43	RCL	322	94	+/-
278	22	22	323	95	=
279	94	+/-	324	22	INV
280	95	=	325	23	LNK
281	22	INV	326	95	=
282	23	LNK	327	99	PRT
283	95	=	328	65	x
284	49	PRD	329	73	RC+
285	23	23	330	18	18
286	43	RCL	331	95	=
287	59	59	332	99	PRT
288	44	SUM	333	72	ST+
289	58	58	334	19	19
290	97	DSZ	335	44	SUM
291	24	24	336	20	20
292	30	TAN	337	01	1
293	98	ADV	338	44	SUM
294	43	RCL	339	17	17
295	23	23	340	44	SUM
296	65	x	341	18	18
297	73	RC+	342	44	SUM
298	18	18	343	19	19
299	95	=	344	97	DSZ
300	99	PRT	345	00	00
301	44	SUM	346	11	A
302	21	21	347	98	ADV
303	43	RCL	348	43	RCL
304	23	23	349	21	21
305	99	PRT	350	99	PRT
306	23	LNK	351	43	RCL
307	94	+/-	352	20	20
308	55	+	353	99	PRT
309	43	RCL	354	92	PTN
310	03	03	355	76	LBL
311	95	=	356	50	IXI
312	99	PRT	357	53	(
313	55	+	358	43	RCL
314	53	(	359	23	23

Title of Program: ESP (Histogram) Card 2

Location	Code	Key	Location	Code	Key
360	22	INV	405	23	23
361	77	GE	406	54	)
362	87	IFF	407	65	x
363	23	LNK	408	43	RCL
364	55	+	409	06	06
365	53	(	410	45	YX
366	43	RCL	411	01	1
367	13	13	412	93	.
368	65	x	413	07	7
369	53	(	414	08	8
370	43	RCL	415	06	6
371	14	14	416	85	+
372	85	+	417	93	.
373	53	(	418	00	0
374	01	1	419	07	7
375	75	-	420	05	5
376	43	RCL	421	05	5
377	14	14	422	65	x
378	54	)	423	43	RCL
379	65	x	424	06	06
380	43	RCL	425	65	x
381	23	23	426	53	(
382	45	YX	427	43	RCL
383	43	RCL	428	23	23
384	13	13	429	35	1/X
385	35	1/X	430	54	)
386	54	)	431	23	LNK
387	23	LNK	432	54	)
388	54	)	433	92	RTN
389	54	)	434	76	LBL
390	92	RTN	435	14	14
391	76	LBL	436	69	DP
392	60	DEG	437	00	00
393	53	(	438	03	3
394	01	1	439	06	6
395	85	+	440	01	1
396	93	.	441	05	5
397	07	7	442	01	1
398	06	6	443	03	3
399	06	6	444	69	DP
400	65	x	445	01	01
401	53	(	446	69	DP
402	01	1	447	05	05
403	75	-	448	91	R/S
404	43	RCL	449	99	FRT

Title of Program: ESP (Histogram) Card 2

Location	Code	Key
450	42	STD
451	03	03
452	03	3
453	01	1
454	03	3
455	03	3
456	69	DP
457	01	01
458	69	DP
459	05	05
460	91	R/S
461	99	PRT
462	42	STD
463	00	00
464	00	0
465	42	STD
466	20	20
467	42	STD
468	21	21
469	02	2
470	05	5
471	42	STD
472	17	17
473	04	4
474	01	1
475	42	STD
476	18	18
477	11	A
478	92	RTN
479	05	5

APPENDIX G

Title of Program: PROGRAM NO. 7: Venturi Scrubber (Histogram) Card 1

Location	Code	Key	Location	Code	Key
000	76	LBL	036	91	R/S
001	11	A	037	99	PRT
002	69	DP	038	42	STD
003	00	00	039	03	03
004	03	3	040	03	3
005	07	7	041	01	1
006	07	7	042	07	7
007	01	1	043	01	1
008	69	DP	044	69	DP
009	02	02	045	02	02
010	69	DP	046	69	DP
011	05	05	047	05	05
012	91	R/S	048	91	R/S
013	99	PRT	049	99	PRT
014	42	STD	050	42	STD
015	01	01	051	12	12
016	03	3	052	02	2
017	03	3	053	07	7
018	07	7	054	06	6
019	01	1	055	03	3
020	69	DP	056	02	2
021	02	02	057	02	2
022	69	DP	058	07	7
023	05	05	059	01	1
024	91	R/S	060	69	DP
025	99	PRT	061	02	02
026	42	STD	062	69	DP
027	02	02	063	05	05
028	02	2	064	91	R/S
029	01	1	065	99	PRT
030	07	7	066	42	STD
031	01	1	067	03	03
032	69	DP	068	04	4
033	02	02	069	01	1
034	69	DP	070	02	2
035	05	05	071	02	2

Title of Program: Venturi Scrubber (Histogram) Card 1

Location	Code	Key	Location	Code	Key
072	07	7	117	91	R/S
073	01	1	118	99	PRT
074	69	DP	119	42	STD
075	02	02	120	04	04
076	69	DP	121	03	3
077	05	05	122	03	3
078	91	R/S	123	00	0
079	99	PRT	124	00	0
080	42	STD	125	00	0
081	06	06	126	00	0
082	16	R	127	69	DP
083	04	4	128	03	03
084	02	2	129	69	DP
085	02	2	130	05	05
086	04	4	131	91	R/S
087	03	3	132	99	PRT
088	06	6	133	42	STD
089	07	7	134	08	08
090	01	1	135	05	5
091	69	DP	136	00	0
092	02	02	137	55	+
093	69	DP	138	43	RCL
094	05	05	139	06	06
095	91	R/S	140	85	+
096	99	PRT	141	09	9
097	42	STD	142	01	1
098	07	07	143	93	.
099	03	3	144	08	8
100	05	5	145	65	*
101	02	2	146	43	RCL
102	03	3	147	05	05
103	03	3	148	45	YX
104	02	2	149	01	1
105	69	DP	150	93	.
106	02	02	151	05	5
107	02	2	152	95	=
108	07	7	153	42	STD
109	00	0	154	10	10
110	00	0	155	65	*
111	00	0	156	02	2
112	00	0	157	55	+
113	69	DP	158	05	5
114	03	03	159	05	5
115	69	DP	160	65	*
116	05	05	161	43	RCL

Title of Program: Venturi Scrubber (Histogram) Card 1

Location	Code	Key	Location	Code	Key
162	05	05	207	02	2
163	65	x	208	07	7
164	43	RCL	209	03	3
165	06	06	210	85	+
166	65	x	211	43	RCL
167	43	RCL	212	01	01
168	04	04	213	54	)
169	55	+	214	55	+
170	43	RCL	215	02	2
171	07	07	216	09	9
172	95	=	217	06	6
173	42	STD	218	93	*
174	09	09	219	02	2
175	43	RCL	220	95	=
176	06	06	221	42	STD
177	65	x	222	11	11
178	43	RCL	223	12	B
179	08	08	224	92	RTN
180	55	+	225	76	LBL
181	53	(	226	16	A'
182	09	9	227	06	6
183	52	EE	228	04	4
184	08	8	229	07	7
185	65	x	230	05	5
186	43	RCL	231	03	3
187	07	07	232	03	3
188	65	x	233	69	DP
189	43	RCL	234	04	04
190	10	10	235	08	8
191	95	=	236	93	*
192	42	STD	237	02	2
193	10	10	238	04	4
194	93	.	239	52	EE
195	00	0	240	04	4
196	06	6	241	94	+/-
197	05	5	242	65	x
198	03	3	243	53	(
199	65	x	244	43	RCL
200	07	7	245	06	06
201	06	6	246	33	X ²
202	55	+	247	65	x
203	43	RCL	248	43	RCL
204	02	02	249	05	05
205	65	x	250	95	=
206	53	(	251	69	DP

Title of Program: Venturi Scrubber (Histogram) Card 1

Location	Code	Key	Location	Code	Key
252	06	06	297	06	06
253	69	DP	298	06	6
254	00	00	299	04	4
255	92	RTN	300	03	3
256	76	LBL	301	02	2
257	12	B	302	00	0
258	43	RCL	303	00	0
259	12	12	304	69	DP
260	42	STD	305	04	04
261	00	00	306	15	E
262	02	2	307	65	x
263	05	5	308	73	RC+
264	42	STD	309	14	14
265	13	13	310	95	=
266	04	4	311	69	DP
267	01	1	312	06	06
268	42	STD	313	44	SUM
269	14	14	314	15	15
270	00	0	315	98	ADV
271	42	STD	316	01	1
272	15	15	317	44	SUM
273	98	ADV	318	13	13
274	06	6	319	44	SUM
275	04	4	320	14	14
276	01	1	321	97	DSZ
277	06	6	322	00	00
278	69	DP	323	02	02
279	04	04	324	74	74
280	73	RC+	325	14	D
281	13	13	326	92	RTN
282	69	DP	327	76	LBL
283	06	06	328	18	C'
284	18	C'	329	53	(
285	42	STD	330	01	1
286	16	16	331	85	+
287	00	0	332	02	2
288	00	0	333	65	x
289	03	3	334	43	RCL
290	03	3	335	11	11
291	03	3	336	55	+
292	07	7	337	73	RC+
293	69	DP	338	13	13
294	04	04	339	65	x
295	15	E	340	53	(
296	69	DP	341	01	1

Title of Program: Venturi Scrubber (Histogram) Card 1

Location	Code	Key	Location	Code	Key
342	93	.	387	15	E
343	02	2	388	53	(
344	04	4	389	43	RCL
345	02	2	390	09	09
346	85	+	391	65	x
347	93	.	392	53	(
348	04	4	393	93	.
349	02	2	394	07	7
350	65	x	395	94	+/-
351	53	(	396	75	-
352	93	.	397	13	C
353	08	8	398	65	x
354	07	7	399	43	RCL
355	65	x	400	03	03
356	73	RC*	401	85	+
357	13	13	402	01	1
358	55	+	403	93	.
359	53	(	404	04	4
360	02	2	405	65	x
361	65	x	406	53	(
362	43	RCL	407	53	(
363	11	11	408	43	RCL
364	54	)	409	03	03
365	94	+/-	410	65	x
366	54	)	411	13	C
367	22	INV	412	85	+
368	23	LNx	413	93	.
369	54	)	414	07	7
370	54	)	415	54	)
371	92	RTN	416	55	+
372	76	LBL	417	93	.
373	13	C	418	07	7
374	53	(	419	54	)
375	73	RC*	420	23	LNx
376	13	13	421	85	+
377	33	X ²	422	93	.
378	65	x	423	04	4
379	43	RCL	424	09	9
380	10	10	425	55	+
381	65	x	426	53	(
382	43	RCL	427	93	.
383	16	16	428	07	7
384	54	)	429	85	+
385	92	RTN	430	13	C
386	76	LBL	431	65	x

Title of Program: Venturi Scrubber (Histogram) Card 1

Location	Code	Key
432	43	RCL
433	03	03
434	54	)
435	54	)
436	55	+
437	13	C
438	54	)
439	22	INV
440	23	LNX
441	92	RTN
442	76	LBL
443	14	D
444	06	6
445	04	4
446	03	3
447	02	2
448	03	3
449	03	3
450	03	3
451	07	7
452	69	DP
453	04	04
454	43	RCL
455	15	15
456	69	DP
457	06	06
458	06	6
459	04	4
460	03	3
461	02	2
462	01	1
463	07	7
464	69	DP
465	04	04
466	01	1
467	75	-
468	43	RCL
469	15	15
470	95	=
471	69	DP
472	06	06
473	92	RTN

APPENDIX H

Title of Program: PROGRAM NO. 8: Venturi Scrubber (Lognormal)

Location	Code	Key	Location	Code	Key
000	76	LBL	036	75	-
001	16	A'	037	43	RCL
002	42	STD	038	10	10
003	06	06	039	85	+
004	53	(	040	01	1
005	15	E	041	93	.
006	65	x	042	04	4
007	19	D'	043	65	x
008	54	)	044	53	(
009	92	RTN	045	53	(
010	76	LBL	046	43	RCL
011	15	E	047	10	10
012	53	(	048	85	+
013	43	RCL	049	93	.
014	06	06	050	07	7
015	33	X ²	051	54	)
016	65	x	052	55	+
017	43	RCL	053	93	.
018	08	08	054	07	7
019	65	x	055	54	)
020	13	C	056	23	LNx
021	65	x	057	85	+
022	43	RCL	058	53	(
023	16	16	059	93	.
024	54	)	060	04	4
025	42	STD	061	09	9
026	10	10	062	55	-
027	53	(	063	53	(
028	53	(	064	93	.
029	43	RCL	065	07	7
030	19	19	066	85	+
031	65	x	067	43	RCL
032	53	(	068	10	10
033	93	.	069	54	)
034	07	7	070	54	)
035	94	+/-	071	54	)

Title of Program: Venturi Scrubber (Lognormal)

Location	Code	Key	Location	Code	Key
072	55	+	117	85	-
073	43	RCL	118	02	2
074	10	10	119	65	x
075	65	x	120	43	RCL
076	43	RCL	121	22	22
077	08	08	122	55	-
078	54	)	123	43	RCL
079	22	INV	124	06	06
080	23	LNx	125	65	x
081	54	)	126	53	(
082	92	RTN	127	01	:
083	76	LBL	128	93	.
084	13	C	129	02	2
085	53	(	130	04	4
086	93	.	131	06	6
087	00	0	132	85	+
088	06	6	133	93	.
089	05	5	134	04	4
090	03	3	135	02	2
091	65	x	136	65	x
092	07	7	137	53	(
093	06	6	138	93	.
094	55	+	139	08	8
095	43	RCL	140	07	7
096	21	21	141	65	x
097	65	x	142	43	RCL
098	53	(	143	06	06
099	02	2	144	55	+
100	07	7	145	53	(
101	03	3	146	02	2
102	85	+	147	65	x
103	43	RCL	148	43	RCL
104	07	07	149	22	22
105	54	)	150	54	)
106	55	+	151	54	)
107	02	2	152	94	+/-
108	09	9	153	22	INV
109	06	6	154	23	LNx
110	93	.	155	54	)
111	02	2	156	54	)
112	54	)	157	92	RTN
113	42	STD	158	76	LBL
114	22	22	159	19	D'
115	53	(	160	53	(
116	01	1	161	43	RCL

Title of Program: Venturi Scrubber (Lognormal)

Location	Code	Key	Location	Code	Key
163	18	18	207	05	05
163	35	1/X	208	36	PGM
164	65	X	209	09	09
165	43	RCL	210	14	D
166	06	06	211	42	STD
167	35	1/X	212	20	20
168	65	X	213	02	2
169	53	(	214	42	STD
170	53	(	215	01	01
171	43	RCL	216	05	5
172	06	06	217	42	STD
173	55	+	218	02	02
174	43	RCL	219	02	2
175	09	09	220	00	0
176	54	)	221	42	STD
177	23	LNK	222	05	05
178	33	X ²	223	93	.
179	55	+	224	01	1
180	43	RCL	225	05	5
181	17	17	226	42	STD
182	54	)	227	03	03
183	22	INV	228	36	PGM
184	23	LNK	229	09	09
185	54	)	230	14	D
186	92	RTN	231	44	SUM
187	76	LBL	232	20	20
188	17	B'	233	05	5
189	25	CLR	234	42	STD
190	93	.	235	01	01
191	01	1	236	02	2
192	42	STD	237	00	0
193	01	01	238	42	STD
194	02	2	239	02	02
195	93	.	240	02	2
196	42	STD	241	00	0
197	02	02	242	42	STD
198	93	.	243	05	05
199	00	0	244	93	.
200	09	9	245	07	7
201	05	5	246	05	5
202	42	STD	247	42	STD
203	03	03	248	03	03
204	02	2	249	36	PGM
205	00	0	250	09	09
206	42	STD	251	14	D

Title of Program: Venturi Scrubber (Lognormal)

Location	Code	Key
252	44	SUM
253	20	20
254	69	DP
255	00	00
256	03	3
257	03	3
258	03	3
259	07	7
260	69	DP
261	04	04
262	43	RCL
263	20	20
264	22	INV
265	52	EE
266	69	DP
267	06	06
268	92	RTN
269	76	LBL
270	11	A
271	47	CMS
272	25	CLR
273	69	DP
274	00	00
275	03	3
276	07	7
277	00	0
278	00	0
279	07	7
280	01	1
281	69	DP
282	02	02
283	69	DP
284	05	05
285	91	R/S
286	99	PRT
287	42	STD
288	07	07
289	03	3
290	03	3
291	00	0
292	00	0
293	07	7
294	01	1
295	69	DP
296	02	02

Location	Code	Key
297	69	DP
298	05	05
299	91	R/S
300	42	STD
301	21	21
302	99	PRT
303	02	2
304	01	1
305	00	0
306	00	0
307	07	7
308	01	1
309	69	DP
310	02	02
311	69	DP
312	05	05
313	91	R/S
314	99	PRT
315	42	STD
316	08	08
317	03	3
318	05	5
319	02	2
320	03	3
321	03	3
322	02	2
323	02	2
324	07	7
325	69	DP
326	02	02
327	69	DP
328	05	05
329	91	R/S
330	99	PRT
331	42	STD
332	11	11
333	69	DP
334	00	00
335	02	2
336	07	7
337	06	6
338	03	3
339	02	2
340	02	2
341	07	7

Title of Program: Venturi Scrubber (Lognormal)

Location	Code	Key	Location	Code	Key
342	01	1	387	14	14
343	69	DP	388	99	PRT
344	02	02	389	03	3
345	69	DP	390	05	5
346	05	05	391	02	2
347	91	R/S	392	03	3
348	99	PRT	393	03	3
349	22	INV	394	02	2
350	52	EE	395	03	3
351	95	=	396	03	3
352	42	STD	397	69	DP
353	12	12	398	02	02
354	69	DP	399	69	DP
355	00	00	400	05	05
356	04	4	401	91	R/S
357	01	1	402	22	INV
358	02	2	403	52	EE
359	02	2	404	95	=
360	07	7	405	99	PRT
361	01	1	406	42	STD
362	69	DP	407	15	15
363	02	02	408	69	DP
364	69	DP	409	00	00
365	05	05	410	03	3
366	91	R/S	411	06	6
367	99	PRT	412	02	2
368	22	INV	413	04	4
369	52	EE	414	02	2
370	95	=	415	02	2
371	42	STD	416	03	3
372	13	13	417	00	0
373	04	4	418	01	1
374	02	2	419	03	3
375	02	2	420	69	DP
376	04	4	421	02	02
377	03	3	422	69	DP
378	06	6	423	05	05
379	07	7	424	91	R/S
380	01	1	425	99	PRT
381	69	DP	426	23	LNK
382	02	02	427	42	STD
383	69	DP	428	10	10
384	05	05	429	33	X ²
385	91	R/S	430	65	X
386	42	STD	431	02	2

Title of Program: Venturi Scrubber (Lognormal)

Location	Code	Key	Location	Code	Key
432	94	+/-	476	13	13
433	95	=	477	33	X ²
434	42	STD	478	22	INV
435	17	17	479	52	EE
436	43	RCL	480	95	=
437	10	10	481	42	STD
438	65	X	482	10	10
439	53	(	483	69	DP
440	02	2	484	00	00
441	65	X	485	01	1
442	89	n	486	06	6
443	54	)	487	01	1
444	34	FX	488	07	7
445	95	=	489	02	2
446	42	STD	490	07	7
447	18	18	491	03	3
448	69	DP	492	07	7
449	00	00	493	01	1
450	01	1	494	03	3
451	06	6	495	69	DP
452	02	2	496	01	01
453	02	2	497	03	3
454	07	7	498	03	3
455	01	1	499	00	0
456	69	DP	500	00	0
457	02	02	501	00	0
458	69	DP	502	00	0
459	05	05	503	00	0
460	91	R/S	504	00	0
461	99	PRT	505	69	DP
462	42	STD	506	02	02
463	09	09	507	69	DP
464	08	8	508	05	05
465	93	.	509	43	RCL
466	02	2	510	10	10
467	04	4	511	99	PRT
468	52	EE	512	25	CLR
469	04	4	513	43	RCL
470	94	+/-	514	13	13
471	65	X	515	65	X
472	43	RCL	516	43	RCL
473	12	12	517	15	15
474	65	X	518	55	+
475	43	RCL	519	09	9

Title of Program: Venturi Scrubber (Lognormal)

Location	Code	Key	Location	Code	Key
520	55	+	564	85	+
521	43	RCL	565	09	9
522	14	14	566	01	1
523	55	+	567	93	.
524	14	D	568	08	8
525	65	X	569	65	X
526	01	1	570	53	(
527	52	EE	571	43	RCL
528	94	+/-	572	12	12
529	08	8	573	54	)
530	95	=	574	45	YX
531	42	STD	575	01	1
532	16	16	576	93	.
533	02	2	577	05	5
534	55	+	578	54	)
535	05	5	579	92	RTN
536	05	5	580	76	LBL
537	65	X	581	12	B
538	43	RCL	582	69	DP
539	12	12	583	00	00
540	65	X	584	04	4
541	43	RCL	585	01	1
542	13	13	586	02	2
543	65	X	587	02	2
544	43	RCL	588	07	7
545	11	11	589	01	1
546	65	X	590	69	DP
547	14	D	591	02	02
548	55	+	592	69	DP
549	43	RCL	593	05	05
550	14	14	594	91	R/S
551	95	=	595	42	STD
552	42	STD	596	13	13
553	19	19	597	99	PRT
554	17	B'	598	02	2
555	92	RTN	599	07	7
556	76	LBL	600	06	6
557	14	D	601	03	3
558	53	(	602	02	2
559	05	5	603	02	2
560	00	0	604	07	7
561	55	+	605	01	1
562	43	RCL	606	69	DP
563	13	13	607	02	02

Title of Program: Venturi Scrubber (Lognormal)

Location	Code	Key
608	69	DF
609	05	05
610	91	R/S
611	99	PRT
612	42	STD
613	12	12
614	61	GTD
615	04	04
616	59	59

APPENDIX I

Title of Program: PROGRAM NO. 9: ESP (Lognormal)

Location	Code	Key	Location	Code	Key
000	76	LBL	036	65	x
001	10	E'	037	89	n
002	72	ST*	038	54	)
003	00	00	039	34	FX
004	65	*	040	95	=
005	01	1	041	10	E'
006	44	SUM	042	92	RTN
007	00	00	043	76	LBL
008	95	=	044	12	B
009	92	RTN	045	99	PRT
010	76	LBL	046	65	x
011	11	A	047	05	5
012	99	PRT	048	42	STD
013	65	x	049	00	00
014	02	2	050	01	1
015	42	STD	051	95	=
016	00	00	052	10	E'
017	01	1	053	91	R/S
018	95	=	054	99	PRT
019	10	E'	055	10	E'
020	91	R/S	056	91	R/S
021	99	PRT	057	99	PRT
022	23	LNK	058	10	E'
023	42	STD	059	92	RTN
024	19	19	060	76	LBL
025	33	X²	061	13	C
026	65	x	062	99	PRT
027	02	2	063	94	+/-
028	95	=	064	65	x
029	94	+/-	065	09	9
030	10	E'	066	42	STD
031	43	RCL	067	00	00
032	19	19	068	01	1
033	65	x	069	95	=
034	53	(	070	87	IFF
035	02	2	071	01	01

Title of Program: ESP (Lognormal)

Location	Code	Key	Location	Code	Key
072	88	DMS	116	65	X
073	10	E'	117	93	.
074	92	RTN	118	00	0
075	76	LBL	119	07	7
076	88	DMS	120	05	5
077	65	X	121	05	5
078	01	1	122	95	=
079	93	.	123	10	E'
080	09	9	124	92	RTN
081	06	6	125	76	LBL
082	09	9	126	15	E
083	52	EE	127	99	PRT
084	94	+/-	128	10	E'
085	03	3	129	91	R/S
086	95	=	130	99	PRT
087	10	E'	131	10	E'
088	92	RTN	132	92	RTN
089	76	LBL	133	76	LBL
090	14	D	134	16	A'
091	99	PRT	135	99	PRT
092	42	STD	136	65	X
093	19	19	137	01	1
094	01	1	138	06	6
095	01	1	139	42	STD
096	42	STD	140	00	00
097	00	00	141	01	1
098	43	RCL	142	95	=
099	19	19	143	10	E'
100	45	YX	144	91	R/S
101	01	1	145	99	PRT
102	93	.	146	10	E'
103	07	7	147	91	R/S
104	08	8	148	99	PRT
105	06	6	149	10	E'
106	95	=	150	87	IFF
107	65	X	151	02	02
108	93	.	152	78	Σ+
109	07	7	153	17	B'
110	06	6	154	76	LBL
111	06	6	155	78	Σ+
112	95	=	156	43	RCL
113	10	E'	157	17	17
114	43	RCL	158	75	-
115	19	19	159	43	RCL

Title of Program: ESP (Lognormal)

Location	Code	Key	Location	Code	Key
160	16	16	205	00	0
161	95	=	206	00	0
162	55	+	207	00	0
163	43	RCL	208	00	0
164	18	18	209	00	0
165	95	=	210	00	0
166	42	STD	211	00	0
167	18	18	212	00	0
168	99	PRT	213	00	0
169	17	B*	214	00	0
170	76	LBL	215	00	0
171	17	B*	216	00	0
172	00	0	217	00	0
173	42	STD	218	00	0
174	19	19	219	00	0
175	42	STD	220	00	0
176	59	59	221	00	0
177	43	RCL	222	00	0
178	16	16	223	00	0
179	42	STD	224	00	0
180	01	01	225	00	0
181	22	INV	226	00	0
182	86	STF	227	00	0
183	01	01	228	00	0
184	22	INV	229	00	0
185	86	STF	230	00	0
186	02	02	231	00	0
187	22	INV	232	00	0
188	52	EE	233	00	0
189	98	ADV	234	00	0
190	43	RCL	235	00	0
191	09	09	236	00	0
192	94	+/-	237	00	0
193	99	PRT	238	00	0
194	98	ADV	239	00	0
195	91	R/S	240	00	0
196	00	0	241	76	LBL
197	00	0	242	10	E*
198	00	0	243	53	<
199	00	0	244	73	RC*
200	00	0	245	00	00
201	00	0	246	65	x
202	00	0	247	53	<
203	00	0	248	01	1
204	00	0	249	44	SUM

Title of Program: ESP (Lognormal)

Location	Code	Key	Location	Code	Key
250	00	00	295	92	RTN
251	54	)	296	76	LBL
252	01	1	297	15	E
253	54	)	298	53	(
254	92	RTN	299	53	(
255	76	LBL	300	10	E'
256	19	D'	301	85	+
257	53	(	302	18	C'
258	72	ST*	303	65	x
259	00	00	304	10	E'
260	65	x	305	85	+
261	53	(	306	18	C'
262	01	1	307	33	X ²
263	44	SUM	308	65	x
264	00	00	309	10	E'
265	54	)	310	54	)
266	01	1	311	19	D'
267	54	)	312	65	x
268	92	RTN	313	10	E'
269	76	LBL	314	54	)
270	18	C'	315	22	INV
271	43	RCL	316	23	LNx
272	01	01	317	19	D'
273	92	RTN	318	53	(
274	76	LBL	319	43	RCL
275	14	D	320	08	08
276	53	(	321	55	+
277	53	(	322	53	(
278	53	(	323	01	1
279	10	E'	324	85	+
280	55	+	325	10	E'
281	10	E'	326	65	x
282	54	)	327	53	(
283	23	LNx	328	01	1
284	33	X ²	329	75	-
285	55	+	330	17	B'
286	10	E'	331	54	)
287	54	)	332	85	+
288	22	INV	333	10	E'
289	23	LNx	334	65	x
290	55	+	335	53	(
291	18	C'	336	17	B'
292	55	+	337	35	1/X
293	10	E'	338	23	LNx
294	54	)	339	54	)

Title of Program: ESP (Lognormal)

Location	Code	Key
340	54	)
341	55	+
342	53	(
343	17	B'
344	23	LNK
345	55	+
346	10	E'
347	55	+
348	53	(
349	10	E'
350	85	+
351	53	(
352	01	1
353	75	-
354	43	RCL
355	14	14
356	54	)
357	65	X
358	17	B'
359	45	YX
360	10	E'
361	43	RCL
362	13	13
363	35	1/X
364	54	)
365	23	LNK
366	54	)
367	65	X
368	43	RCL
369	09	09
370	54	)
371	22	INV
372	23	LNK
373	92	RTN
374	76	LBL
375	17	B'
376	43	RCL
377	10	10
378	92	RTN
379	76	LBL
380	11	A
381	01	1
382	42	STD
383	00	00
384	53	(

Location	Code	Key
385	53	(
386	14	D
387	65	X
388	15	E
389	54	)
390	65	X
391	53	(
392	18	C'
393	75	-
394	10	E'
395	54	)
396	67	EQ
397	88	DMS
398	53	(
399	18	C'
400	75	-
401	10	E'
402	54	)
403	67	EQ
404	89	n
405	77	GE
406	89	n
407	01	1
408	76	LBL
409	77	GE
410	54	)
411	44	SUM
412	19	19
413	43	RCL
414	18	18
415	44	SUM
416	01	01
417	25	CLR
418	61	GTD
419	11	A
420	76	LBL
421	88	DMS
422	93	.
423	05	5
424	61	GTD
425	77	GE
426	76	LBL
427	89	n
428	93	.
429	05	5

Title of Program: ESP (Lognormal)

Location	Code	Key
430	54	)
431	44	SUM
432	19	19
433	53	(
434	10	E'
435	10	E'
436	65	*
437	43	RCL
438	18	18
439	54	)
440	99	PRT
441	44	SUM
442	59	59
443	18	C'
444	99	PRT
445	91	R/S